EVALUATION OF DELAYS AND ACCIDENTS AT INTERSECTIONS TO WARRANT CONSTRUCTION OF A MEDIAN LANE

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by

R.B. SHAW

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

EVALUATION OF DELAYS AND ACCIDENTS AT INTERSECTIONS

TO WARRANT CONSTRUCTION OF A MEDIAN LANE

To: G. A. Leonards, Director
Joint Highway Research Project

March 22, 1966

From: H. L. Michael, Associate Director
Joint Highway Research Project

File: 8-4-31
Project: C-36-17EE

Attached is a Final Report "Evaluation of Delays and Accidents at Intersections to Warrant Construction of a Median Lane" by Mr. Robert B. Shaw, Graduate Assistant on our staff. The research reported was approved by the Board on March 25, 1965, and has been directed by Professor Harold L. Michael. Mr. Shaw also used the report as his thesis for the MSCE degree.

The results given in the attached report can be used to determine the locations that warrant a median volume. Regression equations are also given which predict delay times and accident rates of through vehicles caused by left-turning vehicles at suburban and rural intersection approaches.

The report is presented to the Board for the record and for acceptance as fulfillment of the research plan.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Secretary

HLM:bc

Attachment

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Final Report

EVALUATION OF DELAYS AND ACCIDENTS AT INTERSECTIONS TO WARRANT CONSTRUCTION OF A MEDIAN LANE

by

Robert B. Shaw
Graduate Assistant

Joint Highway Research Project

File No: 8-4-31

Project No: C-36-17 EE

Purdue University
Lafayette, Indiana

March 22, 1966

ACKNOWLEDGMENTS

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Acknowledgment is also given to the Indiana State Police, Accident Records Division, and the Indiana State Highway Commission for their assistance in the collection of the data.

The sincerest appreciation is given to the author's wife for her confidence, patience, and assistance throughout this study.

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ABSTRACT

Shaw, Robert Blair. MSCE, Purdue University, June 1966. Evaluation of Delays and Accidents at Intersections to Warrant Construction of a Median Lane. Major Professor: Harold L. Michael.

The objective of this study was to evaluate the conditions on which the construction, maintenance, and interest costs for a median lane would be warranted at suburban and rural approaches to an intersection. To achieve this objective, delay times and accident rates to through vehicles caused by left-turning vehicles were analyzed in depth at three right-angle intersections which already possessed median lanes, and at eight right-angle intersections which did not have median lanes.

Seconds of delay per hour to through vehicles caused by left-turning vehicles were determined for the major approaches to the eleven intersections during daylight-weekday hours; 6 AM to 6 PM, Monday through Friday. The accidents caused by left-turning vehicles were collected for an almost five-year period and analyzed to determine accident rates for each major intersection approach. This study found a substantial reduction in the number of accidents attributed to left-turning vehicles and negligible delay times to through vehicles at the intersection approaches which possessed median lanes. The accident rates and delay times were analyzed by a multiple linear regression analysis.

Although this study is based only on daylight-weekday hours, the findings are of considerable value in planning the construction of median

lanes. The total cost reduction estimate for a period of years resulting from the construction of a median lane is used to justify the construction, maintenance, and interest costs of the median lane at an intersection approach.

INTRODUCTION

The tremendous increase in motor vehicle usage during recent years in Indiana (16)* and in the United States (1) has greatly affected highway operation. This increase in motor vehicle usage has created an added demand on all components of the highway system resulting in increased operating costs to the motoring public. Intersections are an important component of this system and the increased travel volumes have created congestion at many approaches in the urban, suburban, and rural areas. This study investigated one possible technique for congestion relief at suburban and rural intersection approaches.

The increased congestion at approaches to intersections is a cause for many of the critical problems in highway traffic operations and control (15). Where the intersection is at grade, streams of turning and crossing vehicles must join and cross each other. The points within the intersectional area used in common by these intersecting streams are focal points of accidents and delay. Delays result when vehicles in different streams wish to pass through these focal points at the same time. Accidents result when drivers make mistakes in judgment of the time and place that intersecting movements will occur.

The time and place of conflicts at approaches to intersections may be altered by traffic controls or design. Channelization of intersections at grade has been defined (14) as the separation or regulation of

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* The numbers in parenthesis refer to numbers in the bibliography.

conflicting traffic movements into definite paths of travel by the use of pavement markings, raised islands or other suitable means to facilitate the safe and orderly movement of both vehicles and pedestrians. Channelization is, therefore, used to control the place of conflict between intersecting traffic streams and to influence the time element by separating the conflict points and controlling the speeds at which these conflicts occur.

The median lane is one form of channelization used to separate the conflict points between left-turning vehicles and through vehicles. The median lane provides a temporary storage location for vehicles waiting to make a left-turn movement as shown in Figure 1.

FIGURE 1 - TYPICAL INTERSECTIONS ILLUSTRATING STORAGE LOCATION FOR LEFT-TURNING VEHICLES.

PURPOSE AND SCOPE

The objective of this study was to evaluate the conditions on which the construction, maintenance, and interest costs for a median lane would be warranted at suburban and rural approaches to an intersection. To achieve this objective, delay times and accident rates to through vehicles caused by left-turning vehicles were analyzed in depth at three right-angle intersections which already possessed median lanes and at eight right-angle intersections which did not have median lanes. By assigning a cost to the reduction in delay times and accident rates realized by the presence of a median lane, justification is made for its construction at an intersection approach.

THE STUDY LOCATIONS

The eleven intersections referred to in this study are located within a sixty mile radius of Lafayette-West Lafayette, Indiana (Figure 2). These intersections are located on highways near the cities of Lafayette-West Lafayette, Kokomo, and Indianapolis. The approximate 1965 populations of these urban areas are 65,000, 50,000, and 500,000, respectively. These eleven intersections possess the following characteristics:

1. Signal or stop controlled,
2. Four approaches,
3. Right-angle,
4. Parking restricted, and
5. Located in suburban or rural areas.

A large percentage of the traffic using these intersections is through traffic destined for Chicago, Indianapolis, Fort Wayne, or South Bend. The 1965 major street weekday ADT's for the intersections ranged from 7,100 to 27,500. A summary of the characteristics for the study intersections is shown in Tables 1 and 2.

FIGURE 2 - MAP OF INDIANA WITH RELATIVE LOCATIONS OF STUDY INTERSECTIONS.

TABLE 1

SUMMARY CHARACTERISTICS OF STUDY INTERSECTIONS WITHOUT MEDIAN LANES

Intersection	Location	Type of Area	Type of Signalization	Weekday Approach * ADT Plus Weekday Opposing ADT
U. S. 52 By-Pass & Union Street	Lafayette	Surburban	Fixed Time	17,500
U. S. 52 By-Pass & S. R. 26	Lafayette	Suburban	Fixed Time	18,000
U. S. 52 By-Pass & Salisbury Street	Lafayette	Suburban	Semi-Traffic Actuated	15,800
U. S. 52 & U. S. 23 (S. R. 53)	Lafayette	Rural	Stop Sign Controlled (Flasher)	7,100
S. R. 100 & 56th Street	Indianapolis	Rural	Fully Traffic Actuated	10,500
S. R. 100 & Fall Creek Road	Indianapolis	Rural	Stop Sign Controlled (Flasher)	7,600
S. R. 100 & U. S. 31	Indianapolis	Suburban	Fully-Traffic Actuated	12,900
U. S. 35 (S. R. 22) & U. S. 31 By-Pass)	Kokomo	Suburban	Fully-Traffic Actuated	9,500

* Weekday ADT's based on 1965 volume data.

TABLE 2

SUMMARY CHARACTERISTICS OF STUDY INTERSECTIONS WITH MEDIAN LANES

Intersection	Location	Type of Area	Type of Signalization	Weekday Approach * ADT Plus Weekday Opposing ADT
U. S. 31 & U. S. 35 (S. R. 22)	Kokomo	Suburban	Fully-Traffic Actuated	22,000
U. S. 31 & S. R. 26	Kokomo	Rural	Fully-Traffic Actuated	15,100
S. R. 100 & 30th Street	Indianapolis	Suburban	Fully-Traffic Actuated	27,500

* Weekday ADT's based on 1965 volume data.

REVIEW OF LITERATURE

There has been very little study specifically relating delay times, accident rates, and economics to the installation of median lanes at intersection approaches. This review of literature has, therefore, been restricted to a discussion of several related studies concerning delay measuring methods and accident involvement of left-turning vehicles, and of the one study found which developed a warrant for the construction of left-turn refuge lanes.

Delay Time

Intersections are a major cause of operational delays on highways. Operational delay is that delay caused by the interference between components of traffic (7). The time consumed while waiting at a stop sign for cross traffic to clear, the time losses resulting from congestion, from interference with parking vehicles, and from turning vehicles are all examples of operational delay.

Several studies (6, 10, 12) have been conducted to develop and compare various methods for measuring operational delay at intersections. Among the methods developed to measure delay at an intersection are the following:

1. Spaced serial photo method,
2. Delay meter method,
3. Test car method,

4. 20-pen recorder method,

5. Sampling method, and

6. Combinations of several methods.

These methods can be devised to measure both travel time and stopped time of vehicles travelling through an intersection. Travel time is the elapsed time for a vehicle to travel from a point in advance of the intersection to a point beyond the intersection. Travel time, therefore, includes time losses due to deceleration and acceleration. Stopped time is a measure of the time a vehicle is stopped and does not include time losses due to deceleration and acceleration.

In order to effectively measure the delay time incurred by through vehicles caused by left-turning vehicles, the method employed must measure both the travel times and stopped times of vehicles travelling through an intersection. For the method to be effective, it must also be economical in relation to manpower requirements and ease of obtaining the required data. This study made use of the 20-pen recorder in conjunction with traffic volume counters to measure the delay time to through vehicles caused by left-turning vehicles. This method is described in considerable detail in a later section.

Accident Rate

Extensive research has been conducted to determine accident rate relationships at intersections. These studies indicate a high correlation between traffic volumes and accidents caused by left-turning vehicles.

A study by Baldock (5, 19) attempted to determine the accident involvement of left-turning vehicles in relation to the volume of traffic making the left-turn movement on four-lane divided highways. This study classified accidents caused by left-turning vehicles into the following two categories:

1. Rear-end accidents caused by left-turning vehicles stopping in the moving lane of traffic, and
2. Turning movement accidents caused by a left-turning vehicle being struck by the opposing traffic stream or vice versa.

Baldock reduced the number of accidents to a frequency index which was defined as the number of accidents involving left-turning vehicles per year for an average daily turning volume of one. The relationship between the frequency index and turning volume was depicted graphically (Figure 3) and stated mathematically as follows:

$$F_A = \frac{A_L}{V_L}$$

where F_A is the frequency index,

A_L is the number of accidents per year caused by left-turning vehicles, and

V_L is the average left-turn volume per day.

This study concluded that the accident frequencies occasioned by left-turns on four-lane divided highways increased as the left-turn volume decreased.

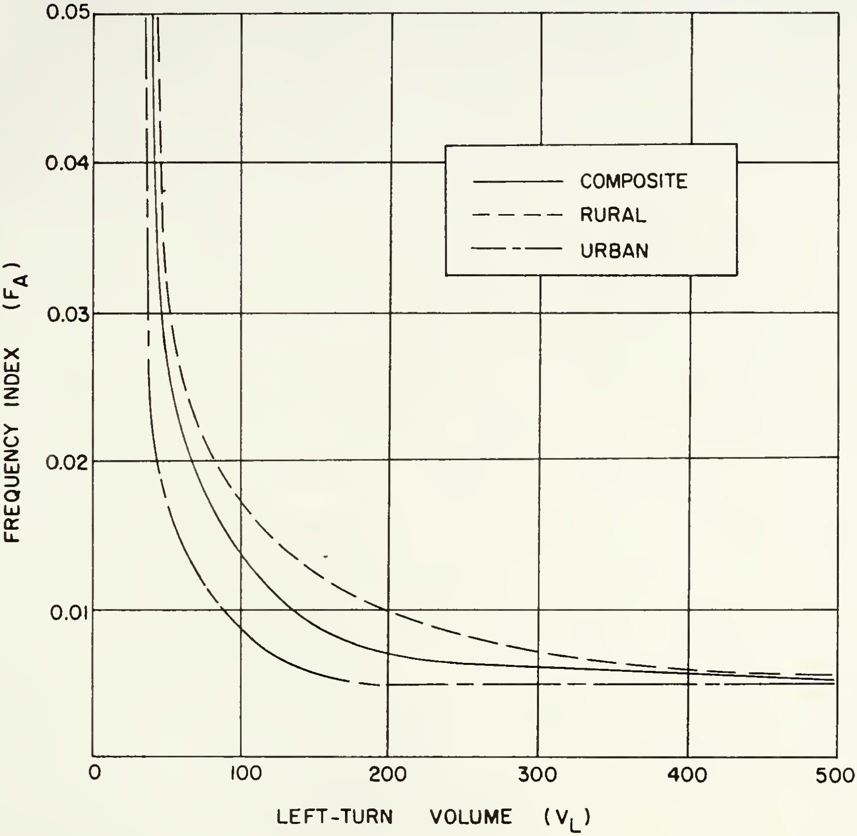

FIGURE 3 - ACCIDENT FREQUENCY INDEX RELATED TO LEFT-TURN VOLUMES.

(SOURCE: ROADS AND STREETS, AUGUST 1946, LEFT-TURN ACCIDENTS)

Warrants for Left-Turn Lane Construction

Very little study has been conducted to develop a warrant for median lane construction. As a result, precise design principles have not been developed nor generally accepted. Much of the current design is based upon the judgment and experience of the designer and the application of recognized principles of geometric highway design (13).

A study by Failmezger (11) attempted to give evidence for the desirability or non-desirability of the construction of a left-turn refuge lane. An index of hazard and a relative warrant were developed which indicated the potential hazard and need by correlating the physical elements, accident records, and cost of construction at a location being considered for the installation of a left-turn refuge lane.

An index of hazard formula was developed based upon the difficulty of a vehicle making a left-turn due to the gap infrequency of opposing vehicles and the physical features of the intersection. This study listed the following three benefits to the motoring public resulting from the installation of a properly designed and placed left-turn refuge lane:

1. Added safety to the motorist,
2. Time savings to the motorist, and
3. Convenience to the motorist.

These benefits were reflected in the index of hazard formula which was stated mathematically as follows:

$$I.\ H. = V_L V_O (1 + F_C + F_E + F_{SA} + F_{SO} + F_S + F_M)$$

where V_L is the average of the eight maximum hours of left-turn movements as abstracted from a standard 16 hour manual vehicle count to include all left-turn movements from the through highway traffic stream,

V_O is the through movement in opposition to the left-turn movement for the same eight-hour period averaged for one direction,

F_C is the clearance width,

F_E is the escape width,

F_{SA} is the sight distance ahead,

F_{SO} is the sight distance overtaking,

F_S is the through vehicular speed, and

F_M is the miscellaneous.

This index of hazard (I. H.) was then incorporated into another expression which considered construction cost and past traffic accident data to determine a relative warrant for construction. The relative warrant (R. W.) formula, derived from an investigation at isolated rural locations which had volumes below that for signalization, was stated mathematically as follows:

$$R.\ W. = \frac{I.\ H.}{C_T}\left(\frac{10 + A_p}{8}\right)$$

where C_T is the total estimated cost of the project,

A_P is the number of preventable accidents for a five-year study period, and

8 is an empirically derived constant to reduce the relative warrant value to near unity.

The relative warrant was used as a tool to obtain uniformity of decision and to give verification of the decision to deny or approve left-turn refuge construction.

The relative warrant formula developed by Failmezger also gives evidence for the desirability or non-desirability of the construction of a left-turn refuge lane at rural intersections which had volumes below

that for signalization. The formula as developed may not be applicable to suburban intersections and to intersections which have volumes sufficient for signalization. The only economic aspect of the relative warrant formula is the cost for construction of the channelization. No attempt was made to include cost estimates of the delay times and accident rates to through vehicles caused by left-turning vehicles.

PROCEDURE

Delay Data

The delay time incurred to a through vehicle caused by a left-turning vehicle was determined at the eleven study intersections during daylight-weekday hours; 6 AM to 6 PM, Monday through Friday.

The method developed to collect the delay time data was designed to be simple, inexpensive, and easily adaptable for use by one or more observers. A typical field setup of the equipment used to study the delay time is shown in Figure 4. The equipment used in the collection of delay data consisted of traffic volume counters, 20-pen recorder, 12 volt battery, push-button box, junction box, pneumatic tubes, and electrical conducting wire as shown in Figure 5. The actual layout of this equipment is shown in Figure 6.

The placement of the traffic counters A and B varied in the suburban and rural areas. Traffic counter A was located prior to the point at which an approaching through vehicle was influenced by the presence of the intersection. Traffic counter B was located beyond the intersection at a point where the through vehicle had resumed its initial approach speed. As the approach speed increased, therefore, the distance between counters A and B increased. This distance between counters A and B was designated as the "zone of influence" and varied from about 800 to 1300 feet.

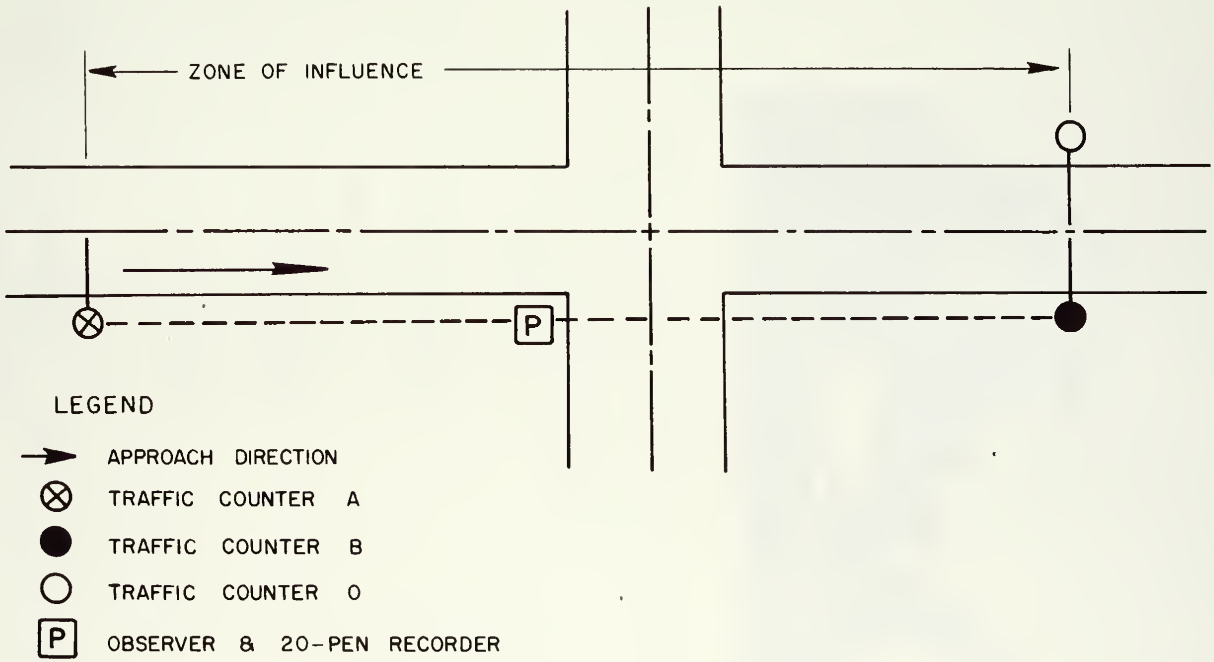

FIGURE 4 - TYPICAL FIELD SETUP OF EQUIPMENT TO STUDY DELAY TIME AT AN INTERSECTION.

JUNCTION BOX

TRAFFIC VOLUME COUNTERS

PUSH-BUTTON BOX

12-VOLT BATTERY

PNEUMATIC TUBES

ELECTRICAL WIRING

20-PEN RECORDER

FIGURE 5 - EQUIPMENT USED TO MEASURE DELAY TIME.

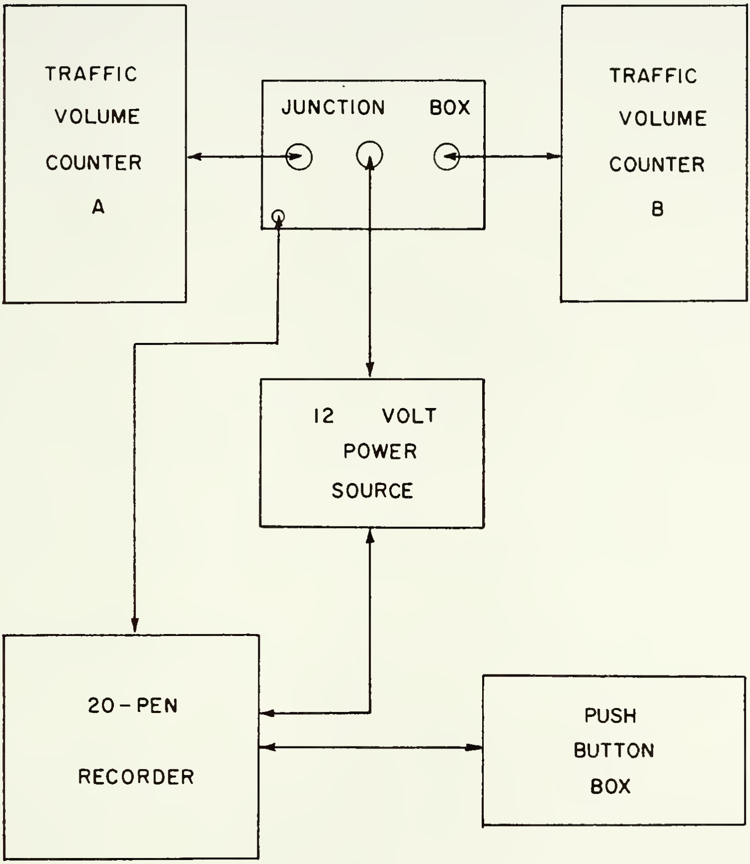

FIGURE 6 - LAYOUT OF EQUIPMENT USED TO MEASURE DELAY TIME.

Approach speed was the determining factor to indicate whether the intersection approach was considered to be located in a suburban or a rural area. Intersection approaches were classified as suburban when the approach speed was greater than 30 miles per hour but less than 45 miles per hour. Rural intersections were those locations where the approach speed was greater than 45 miles per hour. Much greater development of the adjacent land, of course, also existed at the suburban intersections.

Traffic counters A and B were equipped with relay devices which actuated the 20 pen recorder whenever a vehicle axle crossed the pneumatic tubes connected to these two counters. Each axle actuation caused a "pip" on the 20-pen record chart. An opposing traffic volume counter O was located opposite counter B. Each observer had a push-button box which actuated six different pens of the 20-pen recorder as follows:

Pen Number	Description
1	Cancel
2	Stopped time
3	Left-turn vehicular delay
4	Identification of study vehicle
5	Tube A
6	Tube B

Once the equipment was set up at the intersection, an observer selected the first approaching vehicle as a study vehicle. Each study vehicle was identified by pressing the identification button as the vehicle crossed tube A. If the study vehicle turned left or right prior to crossing

tube B, the cancel button was pressed; if the vehicle was delayed by a left-turning vehicle at the intersection, the button signifying a left-turning vehicular delay was pressed; if the vehicle was stopped due to a traffic signal, the stopped time button was pressed both when the vehicle stopped and again when the vehicle started in motion; and finally, when the vehicle crossed tube B, the identification button was again pressed. When a study vehicle had been cancelled or had passed through the zone of influence, the next succeeding vehicle to approach the intersection was selected as a study vehicle. This procedure was repeated for a period of three hours on each approach to be studied at an intersection.

Additional notations were made on the 20-pen record chart to indicate the classification of each study vehicle, and the number of stopped left-turning vehicles present in a queue. This number of stopped left-turning vehicles could later be used to determine the adequate storage length for the proposed median lane.

A study was conducted in order to verify that the delay times incurred to through vehicles during the three-hour study period were not unique to that intersection approach for the particular time and day selected. The three suburban intersections in the Lafayette-West Lafayette area were selected for this purpose. Delay times for specific time periods and days of the week were measured on three successive weeks at the three intersections. It was found that the delay times for any particular time and day at a specified intersection approach were not significantly different at the 95 percent level of confidence. As a result, it was concluded that adequate samples of delay time at an intersection approach could be obtained during any three consecutive hours for week-day-daylight hours.

The 20-pen recorder was operated at a rate of six inches per minute during the time each approach was studied. The elapsed time in seconds for a study vehicle to pass through the zone of influence was scaled from the 20-pen record charts and recorded in one of the four following categories:

1. No delay,
2. Signal delay,
    a. Total time
    b. Stopped time
    c. Total time minus stopped time
3. Left-turn vehicular delay, and
4. Left-turn vehicular delay and signal delay
    a. Total time
    b. Stopped time
    c. Total time minus stopped time.

A sample section of the 20-pen record chart is shown in Figure 7.

This recorded data was used to determine averages of the hourly totals for each of the four categories, and percentages of the vehicles delayed by a left-turning vehicle and of the vehicles delayed by a left-turning vehicle and a signal. Time differences were then determined for categories 1 and 3, and 2 and 4. The seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour in the approach direction were calculated as follows:

$$Y_D = (V)(P_L)(T_L) + (V)(P_{LS})(T_{LS})$$

where Y_D is the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour in the approach direction,

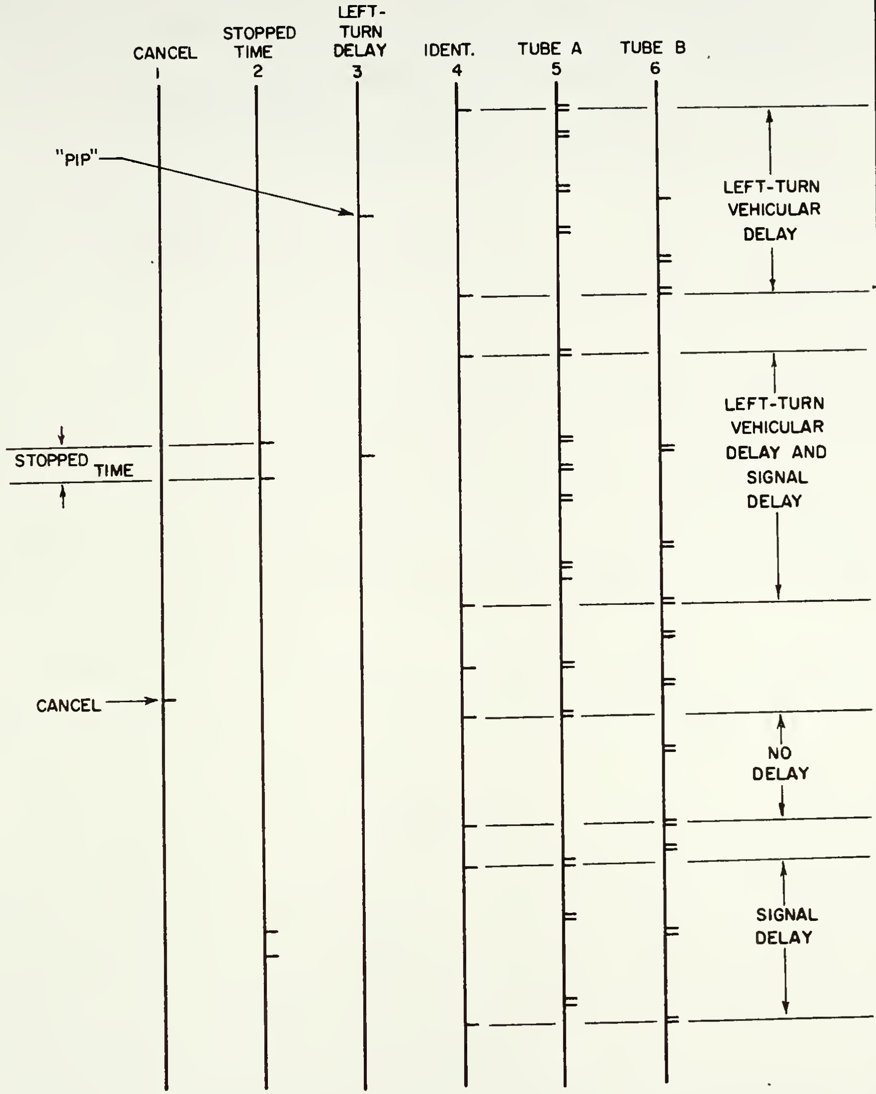

FIGURE 7 - SAMPLE SECTION OF A 20-PEN RECORD CHART.

V is the approach volume per hour of through traffic,

P_L is the percent of through vehicles delayed by a left-turning vehicle,

T_L is the difference in seconds for the average hourly times of categories 1 and 3,

P_{LS} is the percent of through vehicles delayed by a left-turning vehicle and a signal, and

T_{LS} is the difference in seconds for the average hourly times of categories 2 and 4.

It was concluded very early from the field data that the delay time experienced by a through vehicle was negligible at the three locations which possessed median lanes on the approaches to the intersection. Further analysis, therefore, was limited to the delay time experienced by a through vehicle at the approaches to the eight intersections which did not have median lanes.

Those highway characteristics (variables) which might affect delay times in both the suburban and rural areas are shown in Table 3.

Accident Data

An almost five-year study period was chosen in order that an adequate sample of accidents could be obtained. Accidents were collected for the daylight-weekday hours at the eleven study intersections for the period January 1, 1961 through August 31, 1965, and pertinent accident rates were calculated as shown in Tables 4 and 5.

Data on accidents for the three intersections with median lanes clearly indicated the almost total absence of accidents caused by left-turning vehicles. As a result, it was concluded that a median lane will substantially reduce accidents involving left-turning vehicles.

TABLE 3

INDEPENDENT VARIABLES -
SUBURBAN AND RURAL DELAY TIMES

Number	Variable Description
3	Type of Area - Suburban or Rural
4	Flasher (Stop) Controlled
5	Fixed Time Controlled Signalization
6	Semi-Traffic Actuated Controlled Signalization
7	Fully-Traffic Actuated Controlled Signalization
8	Green Time to Cycle Length Ratio of Through Approach
9	Green Time to Cycle Length Ratio of Left-Turn Phase
10	Grade of Approach, Percent
11	Number of Approach Lanes
12	Width of Approach Roadway at the Intersection, Feet
13	Average Speed Through the Intersection for a Non-Delayed Through Vehicle, Feet Per Second
14	Ratio of Width of Access Points to Zone of Influence Length
15	Approach Volume Per Hour, Vehicles Per Hour
16	Opposing Volume Per Hour, Vehicles Per Hour
17	Number of Left-Turning Vehicles in Approach Direction Per Hour
18	Number of Right-Turning Vehicles in Approach Direction Per Hour
19	Number of Commercial Vehicles in Approach Direction Per Hour
20	Number of Approaching Through Vehicles Per Hour Delayed by a Left-Turning Vehicle Only.
21	Number of Approaching Through Vehicles Per Hour Delayed by a Left-Turning Vehicle and a Signal

TABLE 3 (Cont'd.)

Number	Variable Description
22	Ratio of Approach Volume Per Hour to Capacity of Approach Direction
23	Ratio of Opposing Volume Per Hour to Capacity of Opposing Direction
24	Average Number of Stopped Left-Turning Vehicles in an Approach Queue Per Hour
25	Total Volume Per Hour in Approach and Opposing Directions, Vehicles Per Hour

TABLE 4

ACCIDENT RATES AT STUDY INTERSECTIONS WITHOUT MEDIAN LANES*

Intersection	Cause and Type of Accident**			
	Left-Turn		Other	
	Rear-End	Right-of-Way	Rear-End	Right-of-Way
U. S. 52 By-Pass & Union Street	0.151	0.490	0.151	0.075
U. S. 52 By-Pass & S. R. 26	0.183	0.366	0.440	0.073
U. S. 52 By-Pass & Salisbury Street		0.167	0.417	
U. S. 52 & U. S. 231 (S. R. 53)	0.186	0.279		0.466
S. R. 100 & 56th Street		0.126	0.315	0.126
S. R. 100 & Fall Creek Road	0.437	0.262		0.699
S. R. 100 & U. S. 31	0.360	0.514		0.051
U. S. 35 (S. R. 22) & U. S. 31 By-Pass	0.075	1.196	0.149	0.299
Average	0.278	0.604	0.361	0.405

* Accident rates are expressed as the number of accidents per million vehicles for the period January 1, 1961 through August 31, 1965.

** Accidents are classified according to cause: left-turn vehicle or other; and according to type: rear-end or right-of-way.

TABLE 5

ACCIDENT RATES AT STUDY INTERSECTIONS WITH MEDIAN LANES*

Intersection	Type of Accident**	
	Rear-End	Right-of-Way
U. S. 31 & U. S. 35 (S. R. 22)	0.301	0.422
U. S. 31 & S. R. 26	0.220	0.396
S. R. 100 & 30th Street	0.177	0.133
Average	0.240	0.354

* Accident rates are expressed as the number of accidents per million vehicles for the period January 1, 1961 through August 31, 1965.

** No accidents were caused by left-turn vehicles.

The accident analysis was limited to those accidents caused by left-turning vehicles which could have been prevented with the installation of a median lane. The types of accidents considered preventable for this study were the following:

1. Accidents involving a left-turning vehicle with opposing traffic,
2. Sideswipe overtaking accidents involving a left-turning vehicle, and
3. Rear-end accidents that probably resulted from a left-turn movement.

Most of the accident data was collected from the Accidents Records Division of the Indiana State Police. Indiana state law requires that all accidents involving a personal injury, death or property damage of $50 or more be reported to the police. Other accident information was obtained from the files of the West Lafayette police, Indiana State Police Post No. 3 at Lafayette, and the office of the Sheriff in Kokomo. The accident information was recorded from the investigating officer accident report forms (Figure 8 and 9).

In most instances the collision diagram and description of the accident from the investigating officer report form provided the necessary information to distinguish a preventable accident from a non-preventable accident. It was concluded, however, that additional accidents probably were attributed to left-turning vehicles. A study was conducted, therefore, to determine additional rear-end collisions caused by left-turning vehicles which were not recorded as such on the investigating officer report forms. Accident rates for the other rear-end collisions were calculated for the eight intersections without

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DO NOT WRITE IN THIS SPACE

(8)	(9)	(10-11)	(12-13-14-15)	(16)	(2-3-4-5-6-7)
TYPE____	SOURCE____	ANALYSIS____	LOSS____	LOCATION____	ACCIDENT NO.____

TIME

(17-18) (19-20) (21) (22) (23-24)

DATE OF ACCIDENT____ Month Day Year DAY OF WEEK____ TIME OF DAY____:____AM ____:____PM

LOCATION

(25-26) (27) (28-29)

PLACE WHERE ACCIDENT OCCURRED: COUNTY____ CITY OR TOWN____

If accident occurred outside of city limits, indicate distance from nearest city or town limits, using two directions, if necessary. (30-31)

TOWNSHIP____

____Occurred within corporate limits. ____MILES NORTH. ____MILES SOUTH. ____MILES EAST. ____MILES WEST OF.

____Occurred outside corporate limits. LIMITS OF____

(32-33-34) (35-36) City or Town (37-38-39-40)

ROAD ON WHICH ACCIDENT OCCURRED____ AT IT S INTERSECTION WITH____

Name of Street or No. of Highway (US or STATE). If no No., use name. Name or Number of Intersecting Street or Highway

IF NOT AT INTERSECTION____FEET (____N____S____E____W) OF____

Show nearest intersection, house number, or other identifying landmark.

DO NOT MARK IN BOXES

VEHICLES

Total Number of Vehicles Involved

VEHICLE NUMBER 1: (41) (42-43)

YEAR____ MAKE____ TYPE____ Sedan, Truck, Bus, etc. (44)

LICENSE PLATE____ Number State Year

DRIVER____ (Print) Last Name First Middle

ADDRESS____ (Print) Street or R.F.D. (45-46) (47)

____ City and State BIRTH DATE____ AGE____ SEX____ (48)

DRIVER'S LICENSE____ Number State Type (49)

OWNER____ Last Name First Middle

ADDRESS____ Street or R.F.D. City State

PARTS OF VEHICLE DAMAGED____

____ ESTIMATE OF REPAIR $____

VEHICLE REMOVED TO____ BY____

VEHICLE NUMBER 2: (41) (42-43)

YEAR____ MAKE____ TYPE____ Sedan, Truck, Bus, etc. (44)

LICENSE PLATE____ Number State Year

DRIVER____ (Print) Last Name First Middle

ADDRESS____ (Print) Street or R.F.D. (45-46) (47)

____ City and State BIRTH DATE____ AGE____ SEX____ (48)

DRIVER'S LICENSE____ Number State Type (49)

OWNER____ Last Name First Middle

ADDRESS____ Street or R.F.D. City State

PARTS OF VEHICLE DAMAGED____

____ ESTIMATE OF REPAIR $____

VEHICLE REMOVED TO____ BY____

INJURED

Total Number Killed (50)

Injured (51)

(52)

(53-54) (55)

NAME____ AGE____ SEX____ (Print) Last Name First Middle

ADDRESS____ (56) Street or R.F.D. City (57) State

DRIVER____ PASSENGER____ IN VEHICLE NUMBER____

PEDESTRIAN____ Other (EXPLAIN)____

NATURE AND EXTENT OF INJURIES____

(53-54) (55)

NAME____ AGE____ SEX____ (Print) Last Name First Middle

ADDRESS____ (56) Street or R.F.D. City (57) State

DRIVER____ PASSENGER____ IN VEHICLE NUMBER____

PEDESTRIAN____ Other (EXPLAIN)____

NATURE AND EXTENT OF INJURIES____

Mark First One That Applies (58)

1.____	2.____	3.____	4.____
Died as result of accident.	Visible signs of injury, as bleeding wound, distorted limb or had to be carried away.	Other visible injuries, as bruises, swelling, obrasions, limping, etc.	No visible injuries, but complaint of pain or momentary unconsciousness.

1.____	2.____	3.____	4.____
Died as result of accident.	Visible signs of injury, as bleeding wound, distorted limb or had to be carried away.	Other visible injuries, as bruises, swelling, obrasions, limping, etc.	No visible injuries, but complaint of pain or momentary unconsciousness.

DAMAGE TO OTHER PROPERTY____

Name of Object (s) Owner's Name and Address Nature of Damages

____ESTIMATE OF REPAIR $____

This form is approved by the Superintendent, Indiana State Police, pursuant to Burns Indiana Statutes 47-1918, Acts 1939, Ch. 48.

FIGURE 8 - INVESTIGATING OFFICERS ACCIDENT REPORT FORM, SIDE ONE.

(59) CHEMICAL TEST Driver Ped. (Check one)
1 2

0___ ___ ___ No test offered.
1___ ___ ___ Test offered but refused.
2___ ___ ___ Breath test given.
3___ ___ ___ Blood test given.
4___ ___ ___ Urine test given.

(60) ARREST—(Check one)
Driver
1 2

0___ ___ Not arrested.
1___ ___ Arrested for D. U. I.
2___ ___ Arrested for other violation.

(61) SPEED LIMIT ________ **MPH**
(62) SPEED BEFORE ACCIDENT
Veh 1______MPH Veh 2______MPH

(63) CONTRIBUTING CIRCUMSTANCES INDICATED
Driver
1 2

1___ ___ Speed too fast.
2___ ___ Failed to yield right-of-way.
3___ ___ Drove left of center.
4___ ___ Improper overtaking.
5___ ___ Passed stop sign.
6___ ___ Disregarded traffic signal.
7___ ___ Followed too closely.
8___ ___ Made improper turn.
9___ ___ Other improper driving.
10___ ___ Inadequate brakes.
11___ ___ Improper lights.
12___ ___ Had been drinking.

(64) VEHICLE DEFECTS
Driver
1 2

0___ ___ No defects.
1___ ___ Brakes defective.
2___ ___ Lights defective.
3___ ___ Defective steering.
4___ ___ Puncture or blowout.
8___ ___ Other defects.

(65) VISION OBSCURED
Driver
1 2

0___ ___ Not obscured.
1___ ___ By building/s.
2___ ___ By embankment.
3___ ___ By signboard.
4___ ___ Trees, crops, etc.
5___ ___ By hillcrest.
8___ ___ ________
________ (Specify other)

INDICATE ON THIS DIAGRAM WHAT HAPPENED **DRAW DIAGRAM TO SCALE**

Indicate North by arrow

DESCRIBE WHAT HAPPENED:
Refer to vehicle by number ________

WHAT DRIVERS WERE GOING TO DO BEFORE ACCIDENT:
(66)

Driver No. 1 was headed ___N ___S ___E ___W on ________
(Name or number of street or highway.)

Driver No. 2 was headed ___N ___S ___E ___W on ________
(Name or number of street or highway.)

(Check applicable items for each driver.)

Driver 1 2		Driver 1 2		Driver 1 2	
				5___ ___	Start from parked position.
0___ ___	Passing.	2___ ___	Backing.	6___ ___	Avoiding veh., obj., ped.
1___ ___	Turn right.	3___ ___	Slow or stop.	7___ ___	Skidded before applying brakes.
1___ ___	Turn left.	4___ ___	Going straight ahead.	8___ ___	Skidded after applying brakes.
1___ ___	Make U turn.	5___ ___	Start in traffic lane.	9___ ___	Parked.

WHAT PEDESTRIAN WAS DOING BEFORE ACCIDENT
(67)
Pedestrian was going ___N ___S ___E ___W ___along ___across or into ________
Street or Highway

From ________ to ________
(N. E. corner to S. E. corner or from West side to East side, etc.)

(Check one)
0___ Not in roadway.
1___ Walking in roadway with traffic.
2___ Walking in roadway against traffic.
3___ Pushing or working on vehicle.
4___ Getting on or off vehicle.
5___ Standing in roadway.
6___ Other working in roadway.
7___ Playing in roadway.
8___ Other ________ (Specify actions)
11___ Crossing or entering not at intersection.
12___ Crossing or entering at intersection.

CONDITION OF DRIVERS AND PEDESTRIANS
(Check one)
(68) (70)
Driver Ped.
1 2

0___ ___ ___ Had NOT been drinking.
1___ ___ ___ Obviously drunk.
2___ ___ ___ Ability impaired.
3___ ___ ___ Ability not impaired.
4___ ___ ___ Unknown if impaired.

(69) (71)
11___ ___ ___ Apparently normal.
0___ ___ ___ Eyesight defective.
1___ ___ ___ Hearing defective.
2___ ___ ___ Other defects.
3___ ___ ___ Illness.
4___ ___ ___ Fatigued.
5___ ___ ___ Apparently asleep.
6___ ___ ___ Attention diverted.
7___ ___ ___ Advanced senility.
8___ ___ ___ Other handicaps.
________ (Specify other handicaps)

ROAD

(72) TRAFFIC CONTROL
Driver 1 2
0___ ___ Police officer.
1___ ___ Automatic signal.
2___ ___ Yield right-of-way sign.
3___ ___ Center line marked.
4___ ___ Other lane markings.
5___ ___ Stop sign.
6___ ___ Warning sign or signal.
7___ ___ No passing zone.
8___ ___ All others.

(73) CHARACTER (74) (Check two)
1___ Straight.
2___ Curve.
1___ Level.
2___ On grade.
3___ Hillcrest.

(75) SURFACE (Check one)
1___ Concrete.
2___ Blacktop.
3___ Sand or dirt.
4___ Gravel.
8___ ________ Other

(76) CONDITION (Check one)
1___ Dry.
2___ Wet.
3___ Snow/ice
8___ ________ Other

(77) WEATHER (Check one)
1___ Clear.
2___ Raining.
3___ Snowing.
4___ Fog.
8___ ________ Other

(78) LIGHT (Check one)
1___ Daylight.
2___ Dark.
3___ Dawn or dusk.

(79) KIND OF LOCALITY (Check one to show that area adjacent to roadway for 300' was primarily:)
1___ School or playground.
2___ Industrial or business.
3___ Residential.
4___ Open country.

(80) ROAD DEFECTS
1___ Foreign material on surface.
2___ Loose sand, gravel, etc.
3___ Holes, ruts, dips, bumps, etc.
4___ Defective shoulders.
5___ Obstruction not lighted or signaled.
6___ Standing water, landslide, etc.
7___ Obstructed by previous acc.
8___ All other defects.

WITNESSES
Name________ Address________ Location________
Name________ Address________ Location________

POLICE ACTION
ARRESTS: Name________ Charge________
Name________ Charge________

INVESTIGATION: Time notified of accident______AM ______PM Time of arrival at the scene______AM ______PM
Where else was investigation made?________ Is investigation complete? _____Yes _____No
Were photographs taken? _____Yes _____No Driver report form furnished to _____driver No. 1 _____driver No. 2
*SIGNATURE________ Department________ Date of report________

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FIGURE 9 - INVESTIGATING OFFICERS ACCIDENT REPORT FORM, SIDE TWO.

median lanes and for the three intersections with median lanes (See Tables 4 and 5). The difference in the averages of these two accident rates was then used as a basis to randomly assign additional rear-end accidents which could be considered preventable with the installation of a median lane.

The accident data were analyzed on a yearly basis at each intersection approach to determine an accident rate, number of accidents per million vehicles caused by left-turning vehicles, at each of the eight intersections without median lanes. There were no accidents involving a fatal injury included in this analysis.

Those highway characteristics (variables) which might affect accident rates in both the suburban and rural areas are shown in Table 6.

Volume

In delay and accident studies volume has correlated well with delay times and accident rates. This volume can be represented as an hourly volume or as the annual average weekday traffic (ADT). In this study both the hourly volumes and the weekday ADT were used in the analysis.

The traffic volume counters, used as part of the equipment to measure delay time, were employed simultaneously to obtain the approach and opposing volumes per hour for a given direction of travel. An observer was used to record the number of left-turning and right-turning vehicles, as well as, the classification of vehicles entering the intersection approach during the hours of study. It was, therefore, possible to analyze volumes, turning movements, and commercial vehicles for the same period of time the delay data were collected.

TABLE 6

INDEPENDENT VARIABLES - SUBURBAN AND RURAL ACCIDENT RATES

Number	Variable Description
2	Type of Area, Suburban or Rural
3	Flasher (Stop) Controlled
4	Fixed Time Controlled Signalization
5	Semi-Traffic Actuated Controlled Signalization
6	Fully-Traffic Actuated Controlled Signalization
7	Number of Approach Lanes
8	Width of Approach Roadway at the Intersection, Feet
9	Width of Opposing Roadway at the Intersection, Feet
10	Approach Volume Per Hour at Time the Accident Occurred, Vehicles Per Hour
11	Opposing Volume Per Hour at Time the Accident Occurred. Vehicles Per Hour
12	Weekday Approach. ADT, Vehicles Per Day
13	Weekday Approach ADT Plus Weekday Opposing ADT, Vehicles Per Day
14	Total Intersection Weekday ADT, Vehicles Per Day
15	Ratio of Approach Volume Per Hour to Capacity of Approach Direction
16	Ratio of Opposing Volume Per Hour to Capacity of Opposing Direction
17	Average Speed Through the Intersection for a Non-Delayed Through Vehicle, Feet Per Second

The approach and opposing hourly volumes at the time the accident occurred and the weekday ADT's were correlated with the accident rate. Because volume counts were not available for the entire study period, these hourly volumes were estimated as indicated in the following paragraph.

The traffic volumes obtained at the time the delay data were collected were supplemented by volume data from the Division of Planning, Indiana State Highway Commission. Factors were determined from the volume data collected, from records of the Highway Commission, and from charts depicting the yearly, monthly, daily, and hourly variations in traffic volume during average conditions in Indiana (21). Therefore, by knowing the location, year, month, day, and hour of an accident, the hourly volumes at the time an accident occurred were estimated by applying the appropriate factors to the volume counts taken at each intersection approach.

Capacity

The practical capacity of each intersection was calculated by the method described in the 1965 Highway Capacity Manual (7).

Six of the signalized intersections had paved shoulders on the right side which allowed through vehicles to maneuver around a left-turning vehicle as shown in Figure 10. These paved shoulders also acted as turning lanes but were not designated for this specific movement. In order to determine the effectiveness of the paved shoulders in increasing the practical capacities of these six intersections, reference was made to a study (17) which indicated that each paved shoulder carried

FIGURE 10 - MANEUVERING ON PAVED SHOULDER AROUND LEFT-TURN VEHICLE.

approximately one-third the capacity of a properly constructed and signed turning lane.

The practical capacity was calculated for an extra turning lane if more than one lane existed for a direction of travel. This lane was assumed to be a left-turn only lane if the predominant turning movement at that approach was left, and assumed to be a right-turn only lane if the predominant turning movement at that approach was right. If the additional lane was only a paved shoulder not constructed, signed, or used exclusively as turning lane, only one-third of the turning lane capacity was added to the through lane capacity.

The two stop-controlled intersections were also protected with flashers. Although no precise method was available to evaluate the practical capacity of these two unsignalized intersections, it was assumed that the crossroad traffic interference caused a wave-like behavior to the through traffic which approached the behavior of traffic under signal control (2). Since the crossroad traffic interference caused an uninterrupted flow, the practical capacities of these intersections were computed as if the intersections had been operated under traffic control signals with a green time to cycle length ratio of one.

ANALYSIS OF DATA

Multiple Linear Regression

The many variables for the delay and accident data were analyzed by multiple linear regression. This method provided expressions for predicting the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour, and the number of accidents per million vehicles caused by left-turning vehicles at approaches to intersections in both the rural and suburban areas.

The computer program used in this study for the multiple linear regression analysis was the BIMD-2R, "Stepwise Regression" (18). The program deck was available through the Purdue Statistical Laboratory Library Program.

This program computed a sequence of multiple linear regression equations in a stepwise manner. At each step one variable was added to the regression equation. The variable added was the one which made the greatest reduction in the error sum of squares. Equivalently, it was the variable which had the highest partial correlation with the dependent variable partialed on the variables which had already been added; and equivalently it is the variable which, if it were to be added would have the highest F value. In addition. variables were automatically removed when their F values became too low. This technique is sometimes called the "building up" method.

A flow diagram of the analytical procedure for delay times and accident rates is shown in Figure 11.

Tests were conducted on the delay time and accident rate prediction equations to determine whether the multiple coefficient of determination (R_k^2) for "k" independent variables was significantly greater than the multiple coefficient of determination (R_1^2) for a subset of "l" independent variables (4). The purpose of these tests was to develop simplified equations which could usually and adequately predict delay times and accident rates for both suburban and rural areas by using a fewer number of independent variables at the expense of a slight decrease in the multiple correlation coefficient. An option in the BMD-2R program provided for a summary table listing the order each independent variable entered in the multiple linear regression equation and the corresponding increase in the multiple coefficient of determination (R^2) associated with each new variable. A F-test was used to determine the first independent variable which did not add significantly to the increase in the multiple R^2 given the other independent variable or variables already in the regression equation. For example, tests were conducted to determine whether a significant increase resulted from the addition of a second independent variable given the first independent variable, or from the addition of a third independent variable given the first two independent variables already in the regression equation.

This F-test used to determine this significant increase in the multiple R^2 was stated mathematically as follows:

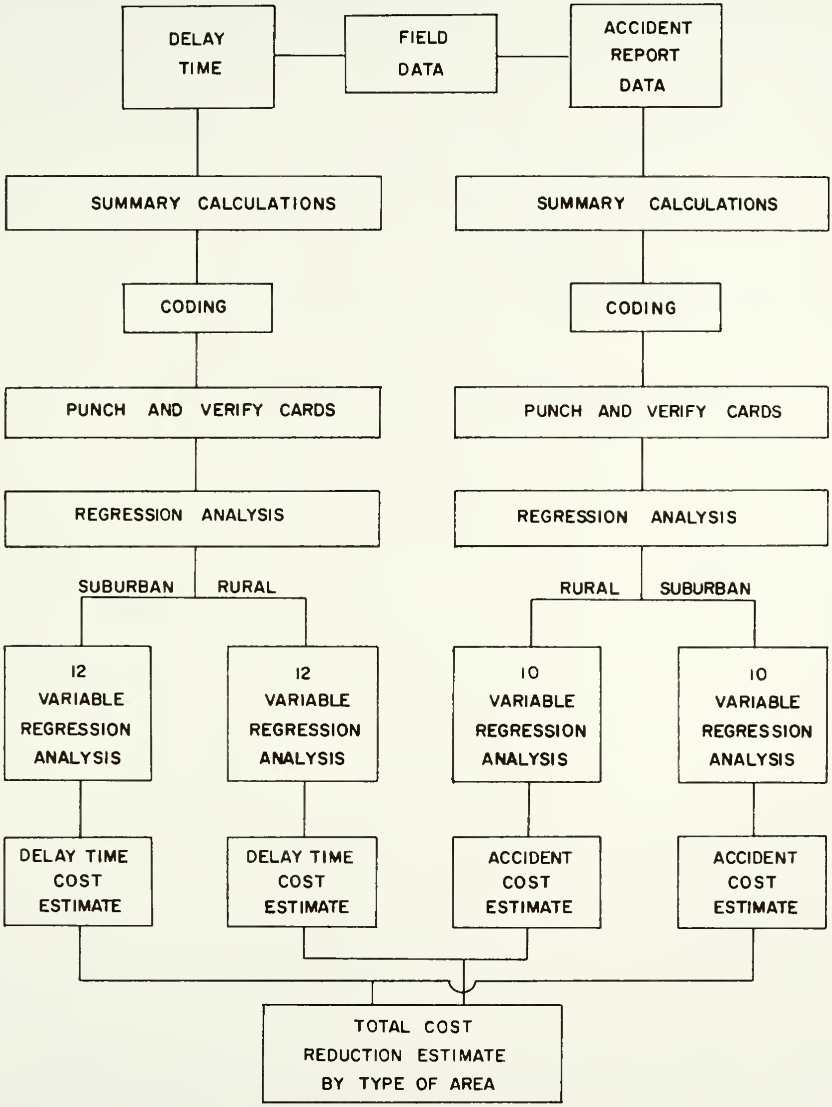

FIGURE 11 - FLOW DIAGRAM OF ANALYTICAL PROCEDURE.

$$F = \frac{\dfrac{R_k^2 - R_1^2}{k - 1}}{\dfrac{1 - R_k^2}{N - k - 1}}$$ with (k-1) and (N-k-1) degrees of freedom

where F is the calculated F value,

R_k^2 is the multiple coefficient of determination for "k" independent variables,

R_1^2 is the multiple coefficient of determination for "l" independent variables.

k is the number of independent variables in the prediction equation to be tested for a significant increase in the multiple R^2,

l is the number of independent variables in the prediction equation used to base the significant increase in the multiple R^2, and

N is the number of observations.

These tests were conducted at a 95 percent level of confidence.

The results of these tests are presented in Tables 8 and 14 as the simplified predictions equations for delay time and accident rates, respectively.

Delay Time

The variables listed in Table 3 represent the independent variables which were considered in the initial analysis for predicting the variability in delay times for both the suburban and rural areas. The results from the initial regression analysis were examined and certain variables deleted.

Table 7 contains the variables that were used in the final analysis to develop separate prediction equations for the suburban and rural areas.

TABLE 7

INDEPENDENT VARIABLES USED IN THE FINAL MULTIPLE LINEAR REGRESSION ANALYSIS OF DELAY TIME DATA FOR SUBURBAN AND RURAL AREAS

Number	Variable Description
8	Green Time to Cycle Length Ratio of Through Approach
10	Grade of Approach, Percent
11	Number of Approach Lanes
12	Width of the Approach Roadway at the Intersection, Feet
13	Average Speed Through the Intersection for a Non-Delayed Through Vehicle, Feet Per Second
15	Approach Volume Per Hour, Vehicles Per Hour
16	Opposing Volume Per Hour, Vehicles Per Hour
17	Number of Left-Turning Vehicles in Approach Direction Per Hour
19	Number of Commercial Vehicles in Approach Direction Per Hour
22	Ratio of Approach Volume Per Hour to Capacity of Approach Direction
23	Ratio of Opposing Volume Per Hour to Capacity of Opposing Direction
26	Total Volume Per Hour in Approach and Opposing Directions, Vehicles Per Hour

The coefficients of the variables used in these multiple linear regression equations are shown in Table 8. These two tables should be used for reference in the following discussion.

Suburban Area

The prediction equation explaining the greatest amount of variability in suburban delay time and developed from the variable coefficients in Table 8 is shown in the following equation:

$$Y_{DS} = 483.788 - 726.881\ X_8 - 33.292\ X_{10} - 338.278\ X_{11}$$

$$- 4.157\ X_{13} + 4.347\ X_{17} - 3.635\ X_{19} - 1027.246\ X_{22}$$

$$+ 1.984\ X_{26}$$

The multiple correlation coefficient equals 0.828. The variables in this equation explain approximately 69 percent (r^2) of the variation in the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour for a suburban intersection approach.

The simple correlation coefficients between each variable and all other variables is shown in Table 9. The independent variables used in the preceding equation possessed the following simple correlation coefficients with the dependent variable, suburban delay time (variable number 25).

TABLE 8

COEFFICIENTS FOR MULTIPLE LINEAR REGRESSION EQUATIONS - DELAY TIME

		Suburban		Rural	
Dependent Variable		Y_{DS}*	Y_{DS}	Y_{DR}*	Y_{DR}
Constant		-620.838	483.788	-242.880	-44.469
Independent Variable	X_8		-726.881		
	X_{10}		- 33.292		50.673
	X_{11}		-338.278		
	X_{12}				-13.514
	X_{13}		- 4.157		
	X_{15}				1.003
	X_{17}	3.505	4.347		5.017
	X_{19}		- 3.635	- 9.119	- 2.735
	X_{22}		-1027.246		547.598
	X_{26}	0.886**	1.984	1.669	0.731
	r	0.791	0.828	0.958	0.986

* This equation represents the simplified prediction equation.

** The coefficient underlined represents the variable that is most significant in the regression equation.

TABLE 9

SIMPLE CORRELATION COEFFICIENTS FOR EACH VARIABLE AND ALL OTHER VARIABLES - DELAY TIME , SUBURBAN AREA

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5	6	7	8	9	10
1	1.000	0.	0.	0.	-0.590	-0.151	0.755	-0.811	C.	-C.2C6
2		0.	0.	0.	0.	0.	0.	0.	C.	C.
3			0.	0.	0.	0.	0.	0.	0.	0.
4				0.	0.	0.	C.	0.	0.	0.
5					1.000	-0.478	-0.632	0.880	C.	C.225
6						1.0C0	-0.378	-0.040	C.	-C.1C7
7							1.000	-0.892	0.	-0.142
8								1.C00	0.	0.181
9									0.	C.
10										1.CCC

VARIABLE NUMBER	11	12	13	14	15	16	17	18	19	20
1	0.360	0.577	-0.514	-0.351	-C.374	-0.316	0.125	0.540	-0.646	-C.306
2	0.	0.	0.	0.	0.	0.	C.	0.	0.	0.
3	0.	0.	0.	0.	C.	0.	C.	0.	0.	0.
4	0.	0.	0.	0.	C.	0.	0.	0.	C.	C.
5	-0.175	-0.491	-0.06C	0.394	C.725	0.797	0.111	-0.041	0.781	C.538
6	-0.105	-0.294	0.351	0.029	-0.107	-0.314	-C.414	-0.436	-0.153	-0.234
7	0.277	0.777	-0.247	-0.441	-0.67C	-0.563	C.249	0.428	-0.688	-0.36C
8	-0.318	-0.676	0.267	0.368	C.742	0.688	-0.037	-0.390	0.861	C.527
9	0.	0.	0.	0.	C.	0.	C.	0.	0.	C.
10	-0.039	-0.034	0.075	0.637	-0.233	0.136	-C.531	0.092	0.117	-0.386
11	1.000	0.265	-0.393	0.120	-0.091	-0.3C5	-0.092	0.493	-0.324	-0.173
12		1.000	-0.009	-0.393	-C.471	-0.448	0.348	0.125	-0.483	-C.118
13			1.00C	-0.224	-C.135	-0.3C0	-0.037	-0.821	0.268	C.082
14				1.000	0.044	0.313	-0.469	0.318	0.137	-C.294
15					1.C00	0.778	0.303	-0.158	0.668	0.77C
16						1.0C0	0.087	0.102	0.626	C.493
17							1.000	-0.200	0.218	C.684
18								1.000	-0.471	-0.390
19									1.0CC	0.587
20										1.CCC

TABLE 9 (CONT'D)

VARIABLE NUMBER	21	22	23	24	25	26
1	0.222	0.028	-0.253	0.320	0.080	-0.368
2	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.
5	0.419	0.386	0.697	0.091	0.498	0.804
6	-0.438	-0.153	-0.338	-0.396	-0.320	-0.216
7	-0.055	-0.272	-0.436	0.253	-0.243	-0.657
8	0.199	0.291	0.598	-0.172	0.390	0.760
9	0.	0.	0.	0.	0.	0.
10	-0.448	-0.423	0.071	0.117	-0.309	-0.064
11	-0.075	-0.249	0.065	-0.111	-0.171	-0.203
12	-0.053	-0.248	-0.326	0.177	-0.132	-0.488
13	-0.460	-0.452	-0.237	-0.431	-0.210	-0.225
14	-0.267	-0.054	0.193	0.083	-0.142	0.180
15	0.678	0.753	0.752	-0.018	0.712	0.950
16	0.591	0.681	0.849	0.209	0.639	0.935
17	0.652	0.510	0.047	0.294	0.477	0.214
18	0.150	0.120	0.166	0.352	-0.015	-0.039
19	0.333	0.277	0.578	-0.018	0.416	0.687
20	0.651	0.609	0.466	-0.011	0.679	0.679
21	1.000	0.845	0.467	0.451	0.746	0.676
22		1.000	0.480	0.350	0.689	0.763
23			1.000	-0.050	0.579	0.846
24				1.000	0.068	0.094
25					1.000	0.718
26						1.000

Independent Variable	Simple Correlation Coefficients
X_8	0.390
X_{10}	-0.309
X_{11}	-0.171
X_{13}	-0.210
X_{17}	0.477
X_{19}	0.416
X_{22}	0.689
X_{26}	0.718

The means and standard deviations of each of the variables are shown in Table 10.

The variable that was the most significant in the multiple linear regression equation for suburban delay time is underlined in Table 8. This variable is the total volume per hour in the approach and opposing directions (X_{26}). Other important variables are the green time to cycle length ratio for the through approach (X_8), the percent grade of the approach (X_{10}), the number of approach lanes (X_{11}), the average speed through the intersection for a non-delayed through vehicle (X_{13}), the number of left-turning vehicles per hour in the approach direction (X_{17}), the number of commercial vehicles per hour in the approach direction (X_{19}), and the ratio of the approach volume per hour to the capacity of the intersection approach (X_{22}).

The simplified prediction equation for suburban delay time is as follows:

$$Y_{DS} = - 620.838 + 3.505\ X_{17} + 0.886\ X_{26}$$

TABLE 10

VARIABLE MEANS AND STANDARD DEVIATIONS - DELAY TIME, SUBURBAN AREA

Variable	Mean	Standard Deviation
3	0.00000	0.00000
4	0.00000	0.00000
5	0.44444	0.50637
6	0.22222	0.42366
7	0.33333	0.48038
8	0.55926	0.12505
9	0.00000	0.00000
10	0.32222	1.63315
11	1.03704	0.19245
12	22.22222	1.33973
13	46.09259	5.23545
14	0.23215	0.16503
15	481.03704	126.78797
16	485.62963	111.76800
17	54.70370	29.84938
18	54.51852	35.43615
19	69.29630	23.00805
20	67.00000	46.20689
21	69.07407	58.76153
22	0.97444	0.18832
23	0.94185	0.14801
24	1.67407	0.67573
26	966.66666	225.00716

The multiple correlation coefficient equals 0.791. The variables in this simplified equation explain approximately 63 percent (r^2) of the variation in the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour for a suburban intersection approach.

The most significant variable in this simplified prediction equation is the total volume per hour in the approach and opposing directions (X_{26}). The other independent variable is the number of left-turning vehicles per hour in the approach direction (X_{17}).

Rural Area

The prediction equation explaining the greatest amount of variability in rural delay time and developed from the variable coefficients in Table 8 is shown in the following equation:

$$Y_{DR} = -44.469 + 50.673\ X_{10} - 13.514\ X_{12} + 1.003\ X_{15}$$

$$+ 5.017\ X_{17} - 2.735\ X_{19} + 547.598\ X_{22} + 0.731\ X_{26}$$

The multiple correlation coefficient equals 0.986. The variables in this equation explain approximately 97 percent (r^2) of the variation in the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour for a rural intersection approach.

The simple correlation coefficients between each variable and all other variables is shown in Table 11. The independent variables used in the preceding equation possessed the following simple correlation coefficients with the dependent variable, rural delay time (variable number 25).

TABLE II

SIMPLE CORRELATION COEFFICIENTS FOR EACH VARIABLE AND ALL OTHER VARIABLES - DELAY TIME, RURAL AREA

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5	6	7	8	9	1C
1	1.000	0.	0.	-0.748	C.	0.	0.748	-0.748	C.	-C.196
2		0.	0.	0.	C.	0.	0.	0.	0.	C.
3			0.	-0.	0.	0.	0.	-0.	0.	0.
4				1.CCO	C.	0.	-1.000	1.CCO	0.	-C.316
5					C.	0.	0.	0.	C.	C.
6						0.	0.	0.	0.	C.
7							1.000	-1.CCO	0.	0.316
8								1.C00	0.	-C.316
9									0.	C.
10										1.CCO

VARIABLE NUMBER	11	12	13	14	15	16	17	18	19	2C
1	-0.911	-0.461	-0.975	-0.382	0.383	0.887	0.588	-0.066	0.475	C.590
2	0.	0.	0.	0.	0.	0.	C.	0.	0.	0.
3	-0.	-0.	-0.	-0.	-C.	-0.	0.	-0.	-C.	C.
4	0.500	-0.191	0.79C	-0.097	-0.485	-0.814	-0.700	-0.389	-0.334	-C.642
5	0.	0.	0.	0.	0.	0.	C.	0.	0.	C.
6	0.	0.	0.	0.	0.	0.	C.	0.	0.	0.
7	-0.500	0.191	-0.790	C.C97	C.485	0.814	0.700	0.389	C.334	C.642
8	0.500	-0.191	0.79C	-0.097	-C.485	-0.814	-0.700	-0.389	-0.334	-C.642
9	0.	0.	0.	0.	0.	0.	C.	0.	0.	C.
10	0.316	0.551	0.036	0.3C7	0.355	0.094	C.345	0.364	-0.285	C.372
11	1.000	0.681	0.894	0.389	-C.395	-0.829	-0.537	0.200	-C.5C8	-0.569
12		1.000	0.414	0.757	C.035	-0.287	-0.041	0.777	-C.1CC	-C.12C
13			1.C0C	0.330	-0.485	-0.928	-0.691	0.060	-0.458	-0.698
14				1.CCO	0.349	-0.102	C.207	0.793	0.229	0.120
15					1.C00	0.666	0.920	0.301	C.541	C.937
16						1.0C0	0.833	0.095	C.51C	C.827
17							1.000	0.188	0.514	0.975
18								1.0C0	0.253	0.127
19									1.CCC	C.471
20										1.CCC

TABLE II (CONT'D)

VARIABLE NUMBER	21	22	23	24	25	26
1	0.511	0.745	0.857	0.425	0.616	0.619
2	0.	0.	0.	0.	0.	0.
3	0.	-0.	-0.	-0.	0.	-0.
4	-0.725	-0.839	-0.933	-0.717	-0.609	-0.659
5	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.
7	0.725	0.839	0.933	0.717	0.609	0.659
8	-0.725	-0.839	-0.933	-0.717	-0.609	-0.659
9	0.	0.	0.	0.	0.	0.
10	0.229	0.277	0.147	0.339	0.380	0.282
11	-0.362	-0.632	-0.719	-0.300	-0.624	-0.604
12	0.138	-0.052	-0.073	0.275	-0.208	-0.051
13	-0.591	-0.825	-0.897	-0.492	-0.720	-0.705
14	0.287	0.103	0.048	0.453	0.010	0.199
15	0.760	0.840	0.625	0.802	0.886	0.954
16	0.703	0.910	0.955	0.688	0.827	0.858
17	0.887	0.963	0.825	0.870	0.907	0.966
18	0.225	0.206	0.254	0.473	0.068	0.245
19	0.489	0.536	0.488	0.513	0.392	0.576
20	0.795	0.938	0.779	0.773	0.973	0.976
21	1.000	0.893	0.783	0.915	0.673	0.804
22		1.000	0.926	0.851	0.888	0.942
23			1.000	0.767	0.750	0.812
24				1.000	0.662	0.827
25					1.000	0.940
26						1.000

Independent Variable	Simple Correlation Coefficient
X_{10}	0.380
X_{12}	-0.208
X_{15}	0.886
X_{17}	0.907
X_{19}	0.392
X_{22}	0.388
X_{26}	0.940

The means and standard deviations of each of the variables are shown in Table 12.

The most significant variable in the multiple linear regression equation for rural delay time is the total volume per hour in the approach and opposing directions (X_{26}). Other important variables are the percent grade of the approach (X_{10}), the width of the approach roadway at the intersection (X_{12}), the approach volume per hour (X_{15}), the number of left-turning vehicles per hour in the approach direction (X_{17}), the number of commercial vehicles per hour in the approach direction (X_{19}), and the ratio of the approach volume per hour to the capacity of the intersection approach (X_{22}).

The simplified prediction equation for rural delay time is as follows:

$$Y_{DR} = - 242.880 - 9.119\ X_{19} + 1.669\ X_{26}$$

The multiple correlation coefficient equals 0.958. The variables in this simplified equation explain approximately 92 percent (r^2) of the variation in the seconds of delay per year caused by left-turning

TABLE 12

VARIABLE MEANS AND STANDARD DEVIATIONS - DELAY TIME, RURAL AREA

Variable	Mean	Standard Deviation
3	1.00000	0.00000
4	0.66667	0.48507
5	0.00000	0.00000
6	0.00000	0.00000
7	0.33333	0.48507
8	0.82333	0.25709
9	0.00000	0.00000
10	- 0.91667	2.10915
11	1.33333	0.48507
12	21.66667	8.90472
13	64.71111	10.82773
14	0.00583	0.00874
15	326.94444	149.22327
16	297.11111	86.95427
17	38.61111	43.51759
18	17.38889	17.35830
19	53.83333	8.34724
20	52.11111	59.17560
21	26.72222	53.64897
22	0.45333	0.38754
23	0.42556	0.33108
24	1.37778	0.51284
26	624.055555	217.04363

vehicles to the total volume of through vehicles per hour for a rural intersection approach.

The most significant variable in this simplified prediction equation is the total volume per hour in the approach and opposing directions (X_{26}). The other independent variable is the number of commercial vehicles per hour in the approach direction (X_{19}).

During the collection of delay data, notations were made on the 20-pen record chart indicating the number of stopped left-turning vehicles in each queue. It was possible, therefore, to determine an average number of stopped left-turning vehicles in a queue per hour. This average number could then be used to determine the adequate storage length for a proposed median lane.

The following ranges of values were found for the average number of stopped left-turning vehicles in a queue per hour, the corresponding approach volume per hour and the percent left-turn vehicles for both the suburban and rural areas.

	Average Number of Stopped Left-Turn Vehicles in a Queue Per Hour	Approach Volume Per Hour	Percent Left-Turn Vehicles
Suburban Area	1.0	479	2.7
	3.7	412	16.5
Rural Area	1.0	163	3.1
	3.0	733	4.1

The required length of the proposed median lane will vary at each intersection approach. The following factors, however, should be considered when determining the length of the proposed storage lane:

1. Approach volume,
2. Percent left-turning vehicles,
3. Average approach speed, and
4. Average number of stopped left-turn vehicles in a queue per hour.

Accident Rate

The variables listed in Table 6 represent the independent variables which were considered in the initial analysis for predicting the variability in accident rates for both the suburban and rural areas. The results from the initial regression analysis were examined and certain variables deleted.

Table 13 contains the variables that were used in the final analysis to develop separate prediction equations for the suburban and rural areas. The coefficients of the variables used in these multiple linear regression equations are shown in Table 14. These two tables should be used for reference in the following discussion.

Suburban Area

The prediction equation explaining the greatest amount of variability in the suburban accident rate and developed from the variable coefficients in Table 14 is shown in the following equation:

$$Y_{AS} = 1.2411 - 1.0882\ X_7 + 0.0029\ X_{10} + 1.3094\ X_{12}$$

$$- 0.8496\ X_{13} + 0.0824\ X_{14} - 1.6262\ X_{16} + 0.0443\ X_{17}$$

The multiple correlation coefficient equals 0.781. The variables in this equation explain approximately 61 percent (r^2) of the variation

TABLE 13

INDEPENDENT VARIABLES USED IN THE FINAL MULTIPLE LINEAR REGRESSION ANALYSIS OF ACCIDENT RATE DATA FOR SUBURBAN AND RURAL AREAS

Number	Variable Description
7	Number of Approach Lanes
8	Width of Approach Roadway at the Intersection, Feet
10	Approach Volume Per Hour at Time the Accident Occurred, Vehicles Per Hour
11	Opposing Volume Per Hour at Time the Accident Occurred, Vehicles Per Hour
12	Weekday Approach ADT, Vehicles Per Day
13	Weekday Approach ADT Plus Weekday Opposing ADT, Vehicles Per Day
14	Total Intersection Weekday ADT, Vehicles Per Day
15	Ratio of Approach Volume Per Hour to Capacity of Approach Direction
16	Ratio of Opposing Volume Per Hour to Capacity of Opposing Direction
17	Average Speed Through the Intersection for a Non-Delayed Through Vehicle, Feet Per Second

TABLE 14

COEFFICIENTS FOR MULTIPLE LINEAR REGRESSION EQUATIONS - ACCIDENT RATE

	Suburban		Rural	
Dependent Variable	Y_{AS}*	Y_{AS}	Y_{AR}*	Y_{AR}
Constant	3.6203	1.2411	1.1333	0.6411
Independent Variable				
X_7	-1.1407	-1.0882		-0.2848
X_8				-0.0110
X_{10}		0.0029	0.0015	0.0045
X_{11}				-0.0077
X_{12}	1.2446	1.3094		
X_{13}	-0.7723**	-.08496		0.8690
X_{14}	0.0371	0.0824	-0.0497	-0.6018
X_{15}				-2.9019
X_{16}		-1.6262		6.0704
X_{17}		0.0443		
r	0.743	0.781	0.609	0.825

* This equation represents the simplified prediction equation.

** The coefficient underlined represents the variable that is most significant in the regression equation.

in the number of accidents per million vehicles caused by left-turning vehicles on a suburban intersection approach.

The simple correlation coefficients between each variable and all other variables is shown in Table 15. The independent variables used in the preceding equation possessed the following simple correlation coefficients with the dependent variable, suburban accident rate (variable number 19).

Independent Variable	Simple Correlation Coefficients
X_7	0.047
X_{10}	-0.313
X_{12}	-0.548
X_{13}	-0.593
X_{14}	-0.243
X_{16}	-0.171
X_{17}	-0.190

The means and standard deviations of each of the variables are shown in Table 16.

The variable that was the most significant in the multiple linear regression equation for suburban accident rate is underlined in Table 14. This variable is the weekday approach ADT plus the weekday opposing ADT (X_{13}). Other important variables are the number of approach lanes (X_7), the approach volume per hour at the time the accident occurred (X_{10}), the weekday approach ADT (X_{12}), the total intersection weekday ADT (X_{14}), the ratio of the opposing volume per hour to the capacity of the opposing intersection approach (X_{16}), and the average speed through the intersection for a non-delayed through vehicle (X_{17}).

TABLE 15

SIMPLE CORRELATION COEFFICIENTS FOR EACH VARIABLE AND ALL OTHER VARIABLES - ACCIDENT RATE , SUBURBAN AREA

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5	6	7	8	9	10
1	1.000	0.	0.	-0.860	-0.165	0.975	0.393	0.779	0.808	-0.466
2		0.	0.	0.	0.	0.	0.	0.	0.	0.
3			0.	0.	0.	0.	0.	0.	0.	0.
4				1.000	-0.336	-0.789	-0.276	-0.678	-0.694	0.554
5					1.000	-0.313	-0.109	-0.251	-0.258	-0.223
6						1.000	0.350	0.847	0.868	-0.413
7							1.000	0.373	0.123	-0.052
8								1.000	0.632	-0.314
9									1.000	-0.378
10										1.000

VARIABLE NUMBER	11	12	13	14	15	16	17	18	19
1	-0.358	-0.922	-0.926	0.569	-0.076	-0.105	-0.406	0.048	0.580
2	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.	0.	0.	0.
4	0.479	0.784	0.789	-0.221	0.211	0.236	0.152	-0.045	-0.462
5	-0.251	0.172	0.174	-0.459	-0.262	-0.254	0.313	0.034	-0.196
6	-0.319	-0.902	-0.909	0.523	-0.042	-0.072	-0.357	0.024	0.594
7	-0.293	-0.362	-0.407	0.492	-0.218	0.076	-0.518	0.078	0.047
8	-0.324	-0.728	-0.740	0.276	-0.088	-0.061	-0.186	0.054	0.473
9	-0.258	-0.763	-0.769	0.326	-0.023	-0.109	-0.255	-0.052	0.512
10	0.856	0.551	0.549	-0.004	0.822	0.845	0.156	-0.023	-0.313
11	1.000	0.423	0.439	0.087	0.877	0.874	0.063	0.005	-0.237
12		1.000	0.990	-0.462	0.163	0.253	0.529	-0.039	-0.548
13			1.000	-0.449	0.189	0.242	0.524	-0.053	-0.593
14				1.000	0.229	0.200	-0.760	0.077	0.243
15					1.000	0.813	-0.015	-0.013	-0.042
16						1.000	0.073	-0.015	-0.171
17							1.000	-0.131	-0.190
18								1.000	0.020
19									1.000

TABLE 16

VARIABLE MEANS AND STANDARD DEVIATIONS - ACCIDENT RATE, SUBURBAN AREA

Variable	Mean	Standard Deviation
2	0.00000	0.00000
3	0.00000	0.00000
4	0.45882	0.50126
5	0.11765	0.32410
6	0.42353	0.49705
7	1.08235	0.27653
8	22.38824	1.30104
9	22.44706	1.34965
10	374.60000	124.97286
11	375.29412	123.76097
12	6.69412	1.66135
13	13.38235	3.25814
14	23.27294	3.96221
15	0.76753	0.22797
16	0.74318	0.22426
17	44.96000	5.21580

The simplified prediction equation for the suburban accident rate is as follows:

$$Y_{AS} = 3.6203 - 1.1407\ X_7 + 1.2446\ X_{12} - 0.7723\ X_{13} + 0.0371\ X_{14}$$

The multiple correlation coefficient equals 0.743. The variables in this simplified equation explain approximately 55 percent (r^2) of the variation in the number of accidents per million vehicles caused by left-turning vehicles on a suburban intersection approach.

The most significant variable in this simplified prediction equation is the weekday approach ADT plus the weekday opposing ADT (X_{13}). Other independent variables are the number of approach lanes (X_7), the weekday approach ADT (X_{12}), and the total intersection ADT (X_{14}).

Rural Area

The prediction equation explaining the greatest amount of variability in the rural accident rate and developed from the variable coefficients in Table 14 is shown in the following equation:

$$Y_{AR} = 0.6411 - 0.2848\ X_7 - 0.0110\ X_8 + 0.0045\ X_{10} - 0.0077\ X_{11} + 0.8690\ X_{13} - 0.6018\ X_{14} - 2.9019\ X_{15} + 6.0704\ X_{16}$$

The multiple correlation coefficient equals 0.825. The variables in this equation explain approximately 68 percent (r^2) of the variation

in the number of accidents per million vehicles caused by left-turning vehicles on a rural intersection approach.

The simple correlation coefficients between each variable and all other variables is shown in Table 17. The independent variable used in the preceding equation possessed the following simple correlation coefficients with the dependent variable, rural accident rate (variable number 19).

Independent Variable	Simple Correlation Coefficients
X_7	-0.126
X_8	-0.323
X_{10}	0.218
X_{11}	0.015
X_{13}	-0.356
X_{14}	-0.391
X_{15}	-0.135
X_{16}	-0.189

The means and standard deviations of each of the variables are shown in Table 18.

The most significant variable in the multiple linear regression equation for rural accident rate is the total intersection weekday ADT (X_{14}). Other important variables are the number of approach lanes (X_7), the width of the approach roadway at the intersection (X_8), the approach volume per hour at the time the accident occurred (X_{10}), the opposing volume per hour at the time the accident occurred (X_{11}), the weekday approach ADT plus the weekday opposing ADT (X_{13}), the ratio of the approach

TABLE 17

SIMPLE CORRELATION COEFFICIENTS FOR EACH VARIABLE AND ALL OTHER VARIABLES - ACCIDENT RATE , RURAL AREA

CORRELATICN MATRIX

VARIABLE NUMBER	1	2	3	4	5	6	7	8	9	10
1	1.000	0.	0.128	0.	0.	-0.128	-0.866	-0.907	-0.931	C.517
2		0.	-0.	0.	0.	-0.	-0.	-0.	-0.	-0.
3			1.000	0.	C.	-1.0C0	0.385	-0.326	-0.254	-0.326
4				0.	0.	0.	C.	0.	0.	0.
5					0.	0.	C.	0.	0.	0.
6						1.0C0	-0.385	0.326	0.254	0.326
7							1.000	0.679	0.739	-0.638
8								1.CC0	0.75C	-0.328
9									1.000	-0.466
10										1.000

VARIABLE NUMBER	11	12	13	14	15	16	17	18	19
1	0.393	0.256	0.179	0.117	0.323	0.245	-0.549	0.438	0.389
2	-0.	-0.	-0.	-0.	-C.	-0.	-C.	0.	-0.
3	-0.442	-0.597	-0.871	-0.926	-C.814	-0.862	0.758	-0.018	0.460
4	0.	0.	0.	0.	C.	0.	0.	0.	0.
5	0.	0.	0.	0.	C.	0.	0.	0.	0.
6	0.442	0.597	0.871	C.926	C.814	0.862	-0.758	0.018	-0.460
7	-0.585	-0.534	-0.601	-0.572	-C.708	-0.661	0.893	-0.407	-0.126
8	-0.253	-0.038	0.023	0.090	-0.111	-0.018	0.320	-0.374	-0.323
9	-0.291	-0.197	-0.03C	0.031	-0.177	-0.116	C.398	-0.385	-0.517
10	0.588	0.702	0.522	0.486	C.777	0.561	-0.609	0.275	0.218
11	1.000	0.146	0.483	0.489	0.654	0.800	-0.628	0.315	0.015
12		1.000	0.796	0.764	0.757	0.502	-0.668	0.232	-0.125
13			1.000	0.992	C.85C	0.820	-C.848	0.335	-0.356
14				1.000	C.865	0.856	-0.854	0.261	-0.391
15					1.000	0.910	-0.896	0.185	-0.135
16						1.000	-C.887	0.213	-0.189
17							1.000	-0.296	0.135
18								1.000	0.025
19									1.000

TABLE 18

VARIABLE MEANS AND STANDARD DEVIATIONS - ACCIDENT RATE, RURAL AREA

Variable	Mean	Standard Deviation
2	1.00000	0.00000
3	0.72222	0.46089
4	0.00000	0.00000
5	0.00000	0.00000
6	0.27778	0.46089
7	1.27778	0.46089
8	19.55556	8.69227
9	20.22222	9.47787
10	240.77778	82.20602
11	224.61111	72.20000
12	3.80556	1.10532
13	7.37778	1.56940
14	10.75000	3.06791
15	0.32278	0.21892
16	0.29889	0.21701
17	64.47778	9.65892

volume per hour to the capacity of the approach direction (X_{15}), and the ratio of the opposing volume per hour to the capacity of the opposing direction (X_{16}).

The simplified prediction equation for the rural accident rate is as follows:

$$Y_{AR} = 1.1333 + 0.0015\ X_{10} - 0.0497\ X_{14}$$

The multiple correlation coefficient equals 0.609. The variables in this simplified equation explain approximately 37 percent (r^2) of the variation in the number of accidents per million vehicles caused by left-turning vehicles on a rural intersection approach.

The most significant variable in this simplified prediction equation is the total intersection weekday ADT (X_{14}). The other independent variable is the approach volume per hour at the time the accident occurred (X_{10}). This simplified equation does not adequately predict the accident rate at a rural intersection approach due to the low multiple correlation coefficient.

APPLICATION OF PREDICTION EQUATIONS

General

The application of the prediction equations is limited to the two extreme conditions under which median lanes might be constructed. It is assumed in this application that a warrant for a median lane exists when the costs of construction of such a lane is equal to or less than the benefits derived from such construction. Such benefits include reduced costs to through vehicles in delay time and number of accidents attributed to left-turning vehicles. Use is made of the simplified prediction equations developed in this study for the delay times and accident rates of through vehicles at an intersection approach.

The first example considers the case where adequate right-of-way exists on both approaches to a signalized intersection of a two-lane highway in a suburban area. As a result, the existing pavement on one or both sides of the highway must be widened for a specified distance on both approaches so that the median lane may be constructed.

The second example considers the case where a median strip at least 16 feet in width is located between the major approaches to a signalized intersection of a four-lane divided highway in a suburban area. This example requires the left-turn lane to be constructed within the existing median. In this example, no changes to the existing through lanes are required.

The basic specifications and construction costs for median lanes were obtained from the Indiana State Highway Commission, Division of Traffic. Several contracts of intersection channelization projects were examined in order to obtain the specifications presented in each example.

Actual costs due to delay were determined for the southbound approach to the intersection of U. S. 52 By-pass and S. R. 26 in Lafayette, Indiana. The cost estimate of delay for all vehicle types was calculated to be $2.25 per hour. This cost estimate includes time and fuel costs for deceleration, acceleration, and idling, and a time cost for comfort and convenience. The unit costs and rates used in the determination of the hourly estimate for delay costs are shown in Table 19.

Average costs for accidents caused by left-turning vehicles were determined from the accident report forms collected for the period January 1, 1961 through August 31, 1965. The average cost of all injuries in 1965 was set at $1900 (20). The average accident costs, which included both property damage and injury costs, were calculated to be $710 in the suburban area and $1352 in the rural area.

A six percent interest rate was used to obtain the annual costs for construction and maintenance of the median lane based on 1965 unit costs.

The prediction equations used to estimate the seconds of delay per hour and the number of accidents per million vehicles to through vehicles caused by left-turning vehicles are based on weekday-daylight hours. These predicted delay times and accident rates, therefore, include only

TABLE 19

1965 UNIT COSTS AND RATES USED TO CALCULATE THE HOURLY DELAY COST*

		Passenger Vehicles	Commercial Vehicles
1.	Fuel	0.32 $/gal.	0.28 $/gal.
2.	Idling	0.007 gal./min.	0.011 gal./min.
3.	Time	1.55 $/hr.	2.80 $/hr.
4.	Comfort and Convenience	0.01 $/veh. mile	0.01 $/veh. mile

* These unit costs and rates are average values based on references 3, 8, and 9.

twelve hours per day for 260 days of the year. For a second calculation, it is assumed that the delay times and accident rates for the weekend-daylight hours are either the same or greater than the delay times and accident rates for the weekday-daylight hours. With this assumption, computations are based on the twelve hours per day for 365 days of the year. In the following two examples, annual cost estimates for delay times and accident rates are presented based on both 260 days and 365 days per year.

It is also assumed that all delays to through vehicles from the left-turn movement and all accidents involving left-turn vehicles will be eliminated by the construction of a median lane. Although this is not completely accurate, it is substantially correct. Furthermore, the prediction equations, by not considering the night hours, 6 PM to 6 AM, give conservative values for both delay and accidents.

Cost estimates for the installation of a median lane are based on construction costs at an existing intersection approach with no additional improvements at that intersection approach. Lower costs would result when additional improvements to an existing intersection are to be made in conjunction with the median lane or when a median lane is to be installed on the intersection approach of a completely new highway.

The following two examples are not to be considered the best possible solutions to the existing intersection approaches, but are to be used only as illustrative examples for the application of the simplified prediction equations developed in this study.

Example - 1

This example attempts to justify the construction of median lanes on both approaches to the intersection of U. S. 52 By-pass and S. R. 26 in Lafayette, Indiana. The U. S. 52 By-pass is a two-lane highway in the suburban area with adequate right-of-way for median lane construction existing on both approaches to the intersection. The conditions before and after construction of the median lanes are shown in Figure 12.

The annual construction, maintenance, and interest costs were determined based on 1965 unit construction costs. No attempt was made to improve the type of signalization nor to include any cost estimate for such improvement. The following construction specifications were used:

1. Median strips
    a. Maximum width of 16 feet
    b. Protected with 6 inch reinforced concrete curb
    c. Constructed of compacted aggregate with hot asphaltic concrete cover
2. Left-turn lanes
    a. Twelve feet in width
    b. Constructed with a 6 inch subbase of compacted aggregate and a 9 inch reinforced concrete pavement
3. Additional pavement area
    a. Widened to provide through lanes 11 feet in width
    b. Constructed with a 6 inch subbase of compacted aggregate and a 9 inch reinforced concrete pavement.

The number of daylight hours of delay per year attributed to left-turning vehicles was determined based on the simplified prediction

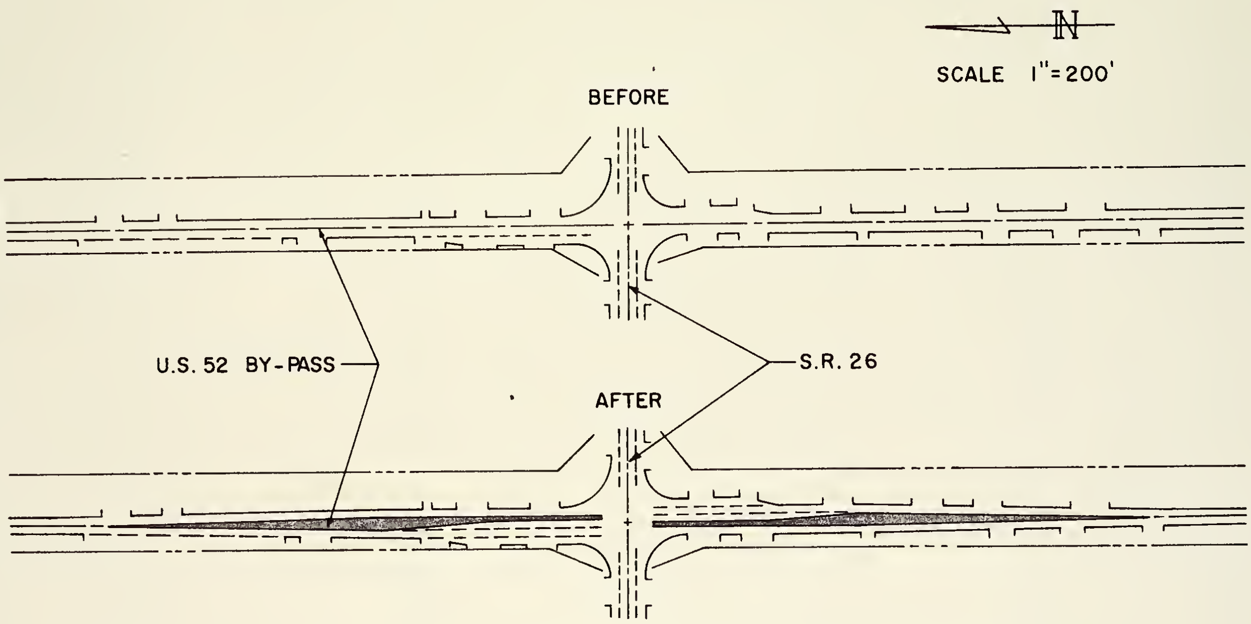

FIGURE 12 - CONDITIONS BEFORE AND AFTER CONSTRUCTION OF MEDIAN LANES AT U.S. 52 BY-PASS & S.R. 26.

equation developed for suburban areas. The equation is stated below with the following 1965 values for the variables:

$$Y_{DS} = -620.838 + 3.505\ X_{17} + 0.886\ X_{26}$$

	Northbound	Southbound
X_{17}	80	32
X_{26}	1107	1107

An annual increase in traffic of three percent was assumed to evaluate variables X_{17} and X_{26} for the succeeding five and ten year periods.

The number of accidents per year caused by left-turning vehicles during the daylight hours was determined based on the simplified prediction equation developed for suburban areas. This equation is stated below with the following 1965 values for the variables:

$$Y_{AS} = 3.6203 - 1.1407\ X_7 + 1.2446\ X_{12} - 0.7723\ X_{13} + 0.0371\ X_{14}$$

	Northbound	Southbound
X_7	1	1
X_{12}	8.80	9.20
X_{13}	18.0	18.0
X_{14}	26.3	26.3

An annual increase in traffic of three percent was also assumed to evaluate variables X_{12}, X_{13}, and X_{14} for the succeeding five and ten year periods.

A summary of the annual cost estimates determined for median lane construction and the resulting reduction in delay time and number of accidents is presented in Table 20. The results indicate that the construction, maintenance, and interest costs for median lanes on both approaches to the intersection of U. S. 52 By-pass and S. R. 26 can be justified over a five-year period using 365 days per year or a ten-year period using either 260 weekdays or 365 days per year.

Example - 2

This example attempts to justify the construction of a median lane on the northbound approach to the intersection of U. S. 31 By-pass and Lincoln Road in Kokomo, Indiana. The U. S. 31 By-pass is a four-lane divided highway in the suburban area with an existing median 40 feet in width. The southbound approach to the intersection already possesses a left-turn lane. The conditions before and after construction of the median lane are shown in Figure 13. Figure 14 illustrates the ease with which a median lane can be constructed on similar four-lane divided highways with existing median of adequate width.

The annual construction, maintenance, and interest costs were determined based on 1965 unit construction costs. No attempt was made to improve the type of signalization nor to include any cost estimate for such improvement. The following construction specifications were used:

1. Left-turn lane

    a. Twelve feet in width

    b. Constructed with a 6 inch subbase of compacted aggregate and a 9 inch reinforced concrete pavement

    c. Separated from the grass median by a 6 inch reinforced concrete pavement.

TABLE 20

SUMMARY COST ESTIMATES FOR EXAMPLE - 1
(U. S. 52 By-Pass & S. R. 26)

		Annual Cost in Dollars			
		1965-1969		1965-1974	
	Costs	260 Days/Yr	365 Days/Yr	260 Days/Yr	365 Days/Yr
I. Median Lanes					
A. Preparation	1,462				
B. Construction	20,822				
C. Finishing	100				
D. Signs and Maintaining Traffic	3,000				
Total Cost	25,984				
E. Maintenance and Miscl. (15.0%)	3,898				
Total Cost	29,882				
F. Annual Cost @ 6.0%					
Interest Rate (C+M+I)		6,078	6,078	4,061	4,061
II. Cost Reduction Estimates					
A. Delay Time (C_{DS})		2,450	3,439	2,838	3,984
B. Accidents (C_{AS})		2,284	3,206	1,894	2,659
Total Reduction Cost (C_{DS} + C_{AS})		4,734	6,645	4,732	6,643
Difference [(C_{DS} + C_{AS}) - (C + M + I)]		-1,344*	+ 567**	+ 671	+2,582

* A negative difference indicates that the annual cost to install median lanes cannot be justified by the annual savings in delay and accidents to through vehicles.

** A positive difference indicates that the annual cost to install median lanes can be justified by the annual savings in delay and accidents to through vehicles.

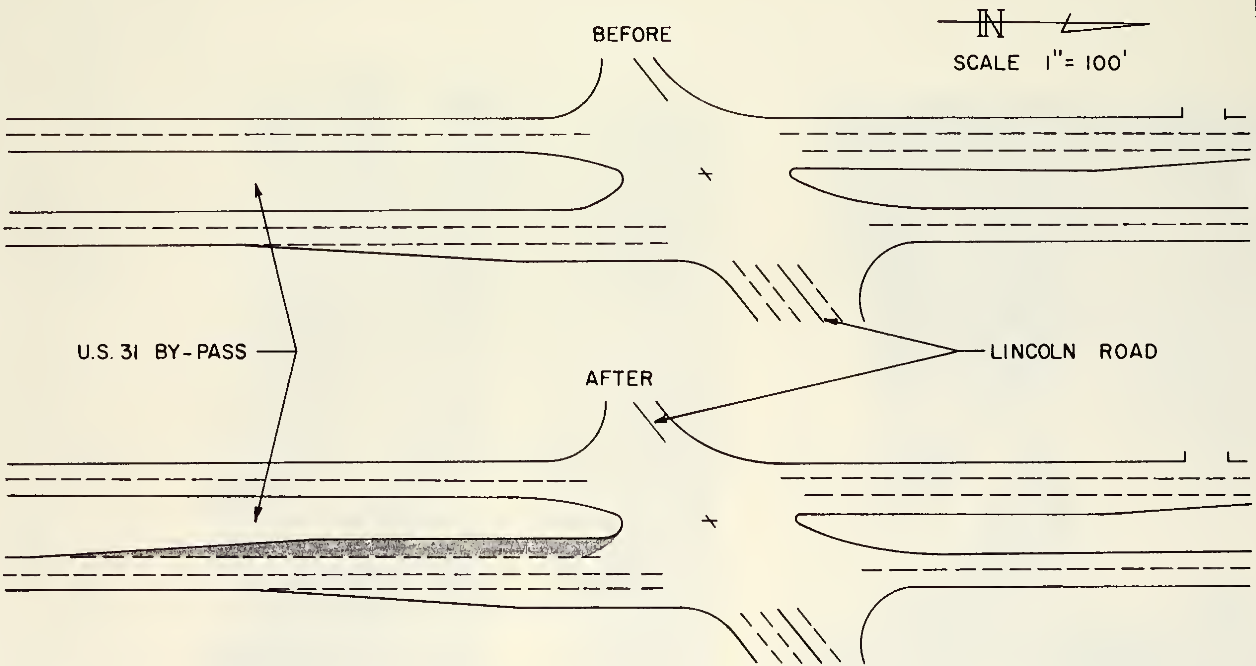

FIGURE 13 - CONDITIONS BEFORE AND AFTER CONSTRUCTION OF A MEDIAN LANE AT U.S. 31 BY-PASS & LINCOLN ROAD.

FIGURE 14 - DIFFERENT FOUR-LANE DIVIDED HIGHWAYS WITH AND WITHOUT MEDIAN LANES.

The number of daylight hours of delay per year attributed to left-turning vehicles was determined based on the prediction equation developed for suburban areas. The simplified equation is stated below with the following 1965 values used for the variables:

$$Y_{DS} = -620.838 + 3.505\, X_{17} + 0.886\, X_{26}$$

	Northbound
X_{17}	7
X_{26}	890

An annual increase in traffic of three percent was assumed to evaluate variables X_{17} and X_{26} for the succeeding five and ten year periods.

The number of accidents per year caused by left-turning vehicles during the daylight hours was determined based on the simplified prediction equation developed for suburban areas. This equation is stated below with the following 1965 values used for the variables:

$$Y_{AS} = 3.6203 - 1.1407\, X_7 + 1.2446\, X_{12} - 0.7723\, X_{13} + 0.0371\, X_{14}$$

	Northbound
X_7	2
X_{12}	9.5
X_{13}	17.4
X_{14}	20.6

An annual increase in traffic of three percent was also assumed to

evaluate variables X_{12}, X_{13}, and X_{14} for the succeeding five and ten year periods.

A summary of the annual cost estimates determined for median lane construction and the resulting reduction in delay time and number of accidents is presented in Table 21. The results indicate that the construction, maintenance, and interest costs for the median lane on the northbound approach to the intersection of U. S. 31 By-pass and Lincoln Road could be justified over both the five-year and the ten-year periods using either 260 weekdays or 365 days per year.

TABLE 21

SUMMARY COST ESTIMATES FOR EXAMPLE - 2
(U. S. 31 BY-PASS & LINCOLN ROAD)

		Annual Cost in Dollars			
		1965-1969		1965-1974	
	Costs	260 Days/Yr	365 Days/Yr	260 Days/Yr	365 Days/Yr
I. Median Lane					
A. Preparation	40				
B. Construction	3,521				
C. Finishing	200				
D. Signs and Maintaining Traffic	1,000				
Total Cost	4,761				
E. Maintenance and Miscl. (15.0%)	714				
Total Cost	5,475				
F. Annual Cost @ 6.0% Interest Rate (C+M+I)		1,114	1,114	744	744
II. Cost Reduction Estimates					
A. Delay Time (C_{DS})		473	664	607	852
B. Accidents (C_{AS})		814	1,427	717	1,007
Total Reduction Cost (C_{DS} + C_{AS})		1,287	2,091	1,324	1,859
Difference [(C_{DS} + C_{AS}) - (C + M + I)]		+ 173*	+ 977	+ 580	+1,115

* A positive difference indicates that the annual cost to install a median lane can be justified by the annual savings in delay and accidents to through vehicles.

RESULTS AND FINDINGS

The results and findings of this study, which evaluated the conditions on which the construction of median lanes at intersection approaches in suburban and rural areas would be warranted, are summarized in the following paragraphs.

1. The presence of a median lane creates negligible delay times and substantially reduces the number of accidents to through vehicles attributed to left-turning vehicles.

2. A warrant for the construction of a median lane which relates the annual cost for construction and maintenance of a median lane to the total estimated benefits derived from a reduction in delay and in accidents for suburban and rural areas is as follows:

$$C_{DS} + C_{AS} \geq C + M + I$$

$$C_{DR} + C_{AS} \geq C + M + I$$

where C_{DS} and C_{DR} are the annual cost reduction estimates for delay time in the suburban and rural areas, respectively,

C_{AS} and C_{AR} are the annual cost reduction estimates for accidents in the suburban and rural areas, respectively, and

$C + M + I$ is the annual construction, maintenance, and interest costs for the median lane.

3. Equations were developed to predict delay times and accident rates for the weekday-daylight hours; 6 AM to 6 PM, Monday through Friday. These equations are as follows:

   a. Delay time, suburban area

$$Y_{DS} = 483.788 - 726.881\, X_8 - 33.292\, X_{10} - 338.278\, X_{11}$$

$$- 4.157\, X_{13} + 4.347\, X_{17} - 3.635\, X_{19}$$

$$- 1027.246\, X_{22} + 1.984\, X_{26}$$

where

Y_{DS} is the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour for a suburban intersection approach,

X_8 is the green time to cycle length ratio of the through approach,

X_{10} is the percent grade of the approach,

X_{11} is the number of approach lanes,

X_{13} is the average speed through the intersection for a non-delayed through vehicle, feet per second,

X_{17} is the number of left-turning vehicles in the approach direction per hour,

X_{19} is the number of commercial vehicles in the approach direction per hour,

X_{22} is the ratio of the approach volume per hour to the capacity of the intersection approach, and

X_{26} is the total volume per hour in the approach and opposing directions, vehicles per hour.

A simplified but adequate equation for predicting delay

time at suburban intersection approaches is as follows:

$$Y_{DS} = -620.838 + 3.505\ X_{17} + 0.886\ X_{26}$$

b. Delay time, rural area

$$Y_{DR} = -44.469 + 50.673\ X_{10} - 13.514\ X_{12} + 1.003\ X_{15}$$

$$+ 5.017\ X_{17} - 2.735\ X_{19} + 547.598\ X_{22}$$

$$+ 0.731\ X_{26}$$

where

Y_{DR} is the seconds of delay per hour caused by left-turning vehicles to the total volume of through vehicles per hour for a rural intersection approach,

X_{10} is the percent grade of the approach,

X_{12} is the width of the approach roadway at the intersection,

X_{15} is the approach volume per hour, vehicles per hour,

X_{17} is the number of left-turning vehicles in the approach direction per hour,

X_{19} is the number of commercial vehicles in the approach direction per hour,

X_{22} is the ratio of the approach volume per hour to the capacity of the intersection approach, and

X_{26} is the total volume per hour in the approach and opposing directions, vehicles per hour.

A simplified but adequate equation for predicting delay time at rural intersection approaches is as follows:

$$Y_{DR} = -242.880 - 9.119\ X_{19} + 1.669\ X_{26}$$

c. Accident rate, suburban area

$$Y_{AS} = 1.2411 - 1.0882\ X_7 + 0.0029\ X_{10} + 1.3094\ X_{12}$$

$$- 0.8496\ X_{13} + 0.0824\ X_{14} - 1.6262\ X_{16}$$

$$+ 0.0443\ X_{17}$$

where

Y_{AS} is the number of accidents per million vehicles caused by left-turning vehicles on a suburban intersection approach,

X_7 is the number of approach lanes,

X_{10} is the approach volume per hour at the time the accident occurred, vehicles per hour,

X_{12} is the weekday approach ADT, vehicles per day,

X_{13} is the weekday approach ADT plus weekday opposing ADT, vehicles per day,

X_{14} is the total intersection ADT, vehicles per day,

X_{16} is the ratio of the opposing volume per hour to the capacity of the opposing intersection approach, and

X_{17} is the average speed through the intersection for a non-delayed through vehicle. feet per second.

A simplified but adequate equation for predicting the accident rate at suburban intersection approaches is as follows:

$$Y_{AS} = 3.6203 - 1.1407\ X_7 + 1.2446\ X_{12} - 0.7723\ X_{13}$$

$$+ 0.0371\ X_{14}$$

d. Accident rate, rural area

$$Y_{AR} = 0.6411 - 0.2848\ X_7 - 0.0110\ X_8 + 0.0045\ X_{10}$$

$$- 0.0077\ X_{11} + 0.8690\ X_{13} - 0.6018\ X_{14}$$

$$- 2.9019\ X_{15} + 6.0704\ X_{16}$$

where

Y_{AR} is the number of accidents per million vehicles caused by left-turning vehicles on a suburban intersection approach,

X_7 is the number of approach lanes,

X_8 is the width of the approach roadway at the intersection, feet,

X_{10} is the approach volume per hour at the time the accident occurred, vehicles per hour,

X_{11} is the opposing volume per hour at the time the accident occurred, vehicles per hour,

X_{13} is the weekday approach ADT plus weekday opposing ADT, vehicles per day,

X_{14} is the total intersection weekday ADT, vehicles per day,

X_{15} is the ratio of the approach volume per hour to the capacity of the approach direction, and

X_{16} is the ratio of the opposing volume per hour to the capacity of the opposing intersection approach.

A simplified but inadequate equation for predicting the accident rate at rural intersection approaches is as follows:

$$Y_{AR} = 1.1333 + 0.0015\ X_{10} - 0.0497\ X_{14}$$

4. Using a life of only five years, it was shown that median lanes were warranted at two example intersections, namely (Example - 1) at the intersection of U. S. 52 By-pass and S. R. 26 in Lafayette and (Example - 2) at the intersection of U. S. 31 By-pass and Lincoln Road in Kokomo.

SUGGESTIONS FOR FUTURE RESEARCH

The results of this study have indicated a warrant for the construction of median lanes based on an evaluation of decreased delay times and accident rates to through vehicles in the suburban and rural areas. The following suggestions are offered as possibilities for future research:

1. This study developed prediction equations for delay times and accident rates based on weekday-daylight hours; 6 AM to 6 PM, Monday through Friday. A similar study is suggested for the remaining hours of the week, including weekends.
2. Delay time information was obtained with the 20-pen recorder in conjunction with traffic volume counters. Other field collection methods should be attempted and the results compared to indicate the limitations of each method.
3. The multiple linear regression technique was used to develop prediction equations for delay time at intersection approaches in the suburban and rural areas. It is recommended also that simulation be used to determine the average delay of the through vehicles due to left-turning vehicles.
4. Some difficulty was encountered when determining the accidents caused by left-turning vehicles. An improved method of recording by the investigating officer on the accident report form all causes of each accident is suggested.

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APPENDIX A

GEOMETRICS OF THE STUDY INTERSECTIONS

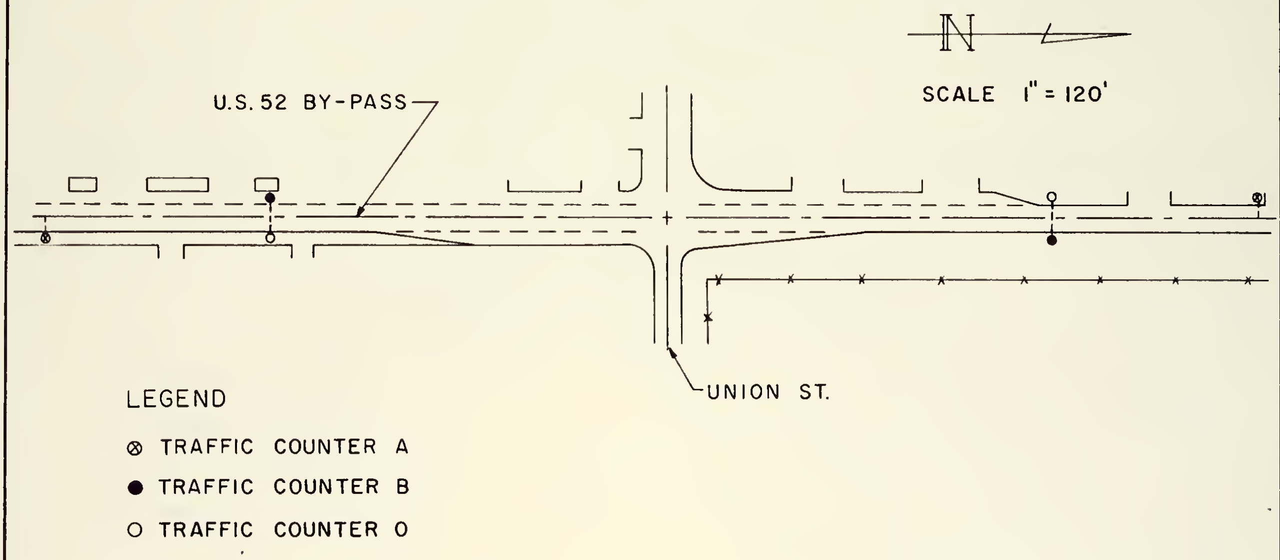

FIGURE 15 - U.S. 52 BY-PASS & UNION ST.

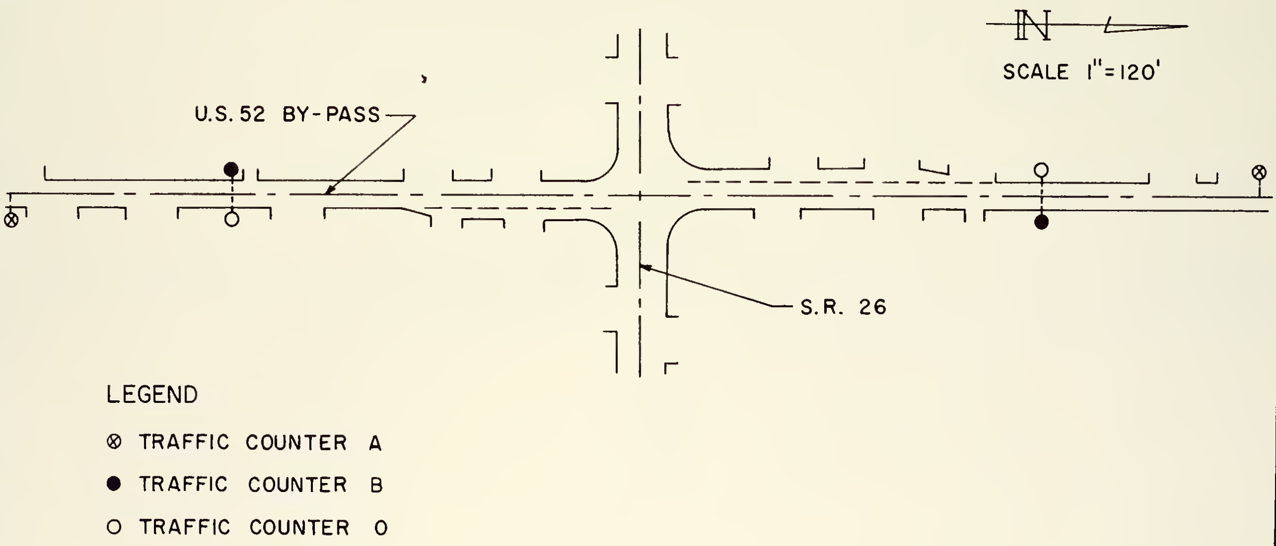

FIGURE 16 - U.S. 52 BY-PASS & S.R. 26

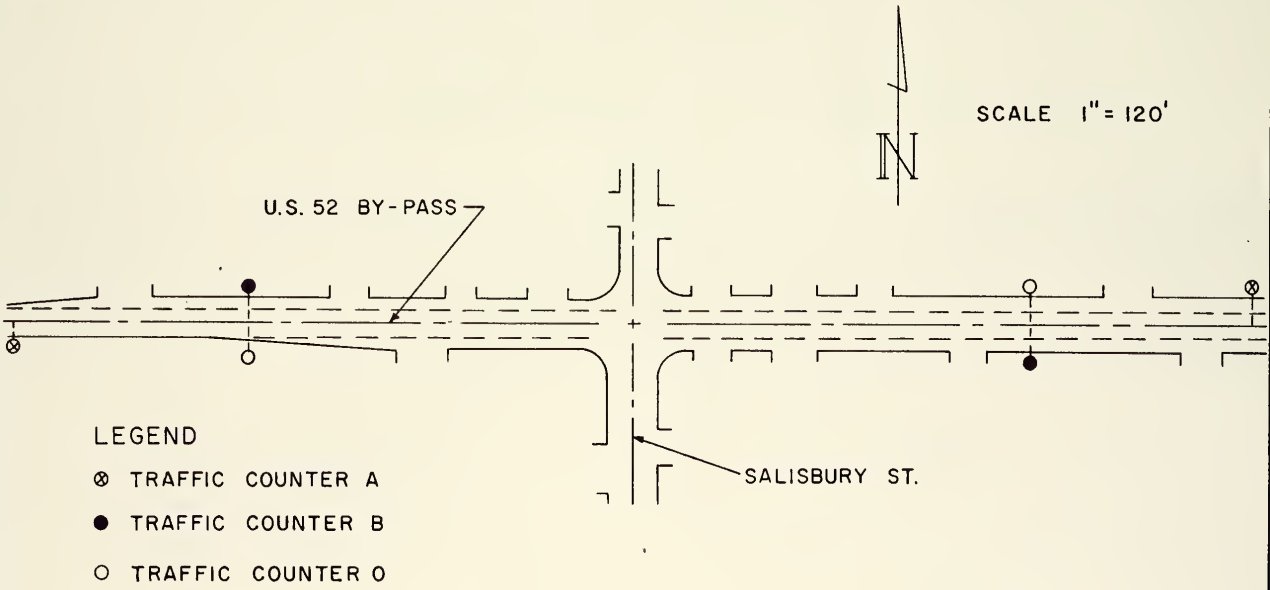

FIGURE 17 - U.S. 52 BY-PASS & SALISBURY ST.

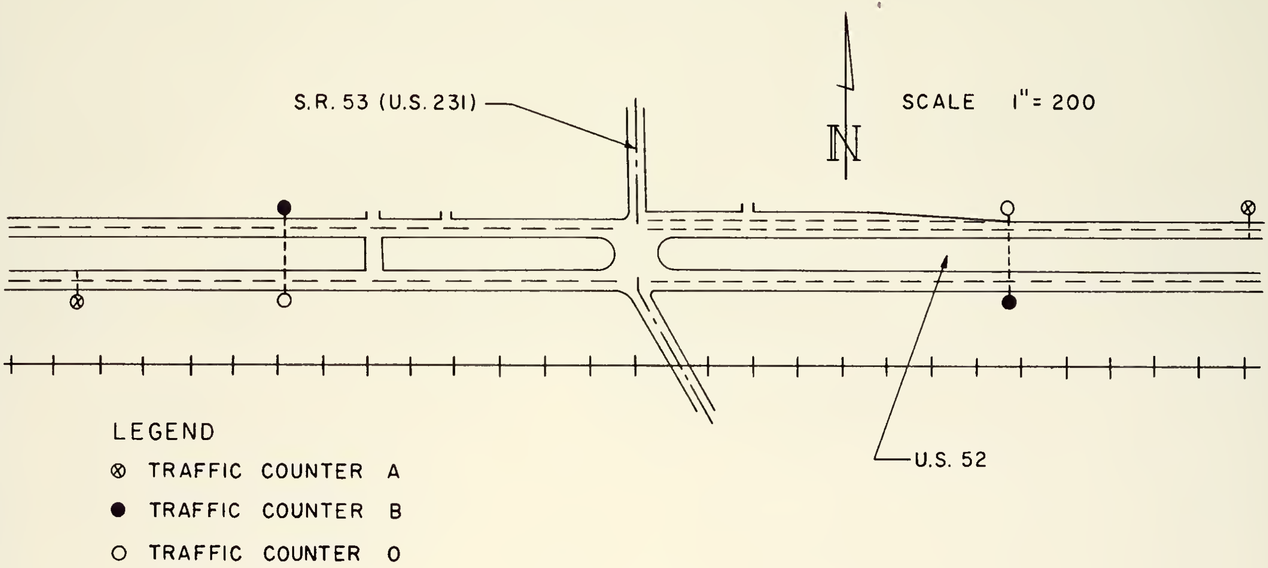

FIGURE 18 - U.S. 52 & S.R.53 (U.S. 231)

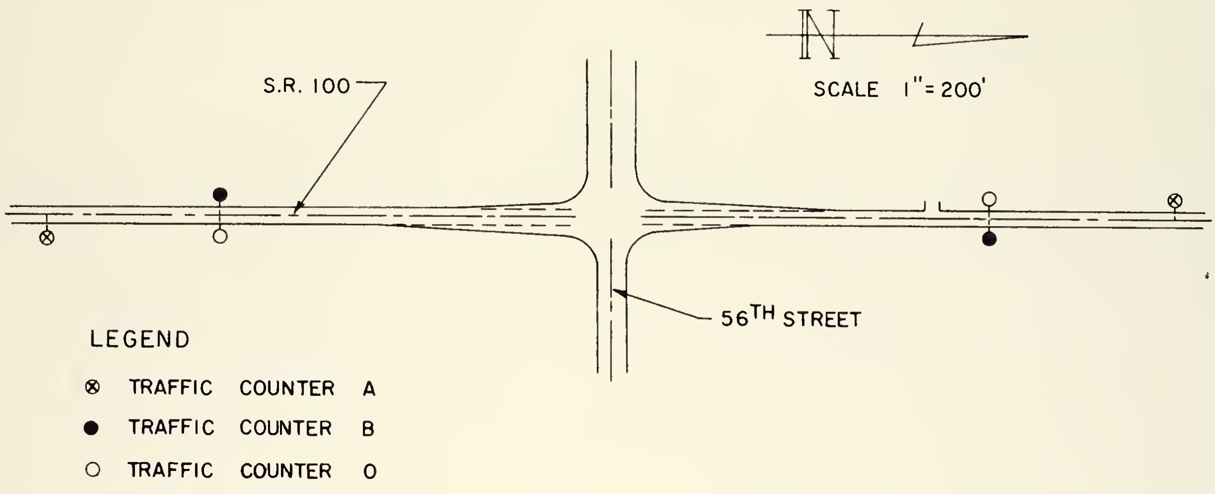

FIGURE 19 - S.R.100 & 56TH STREET

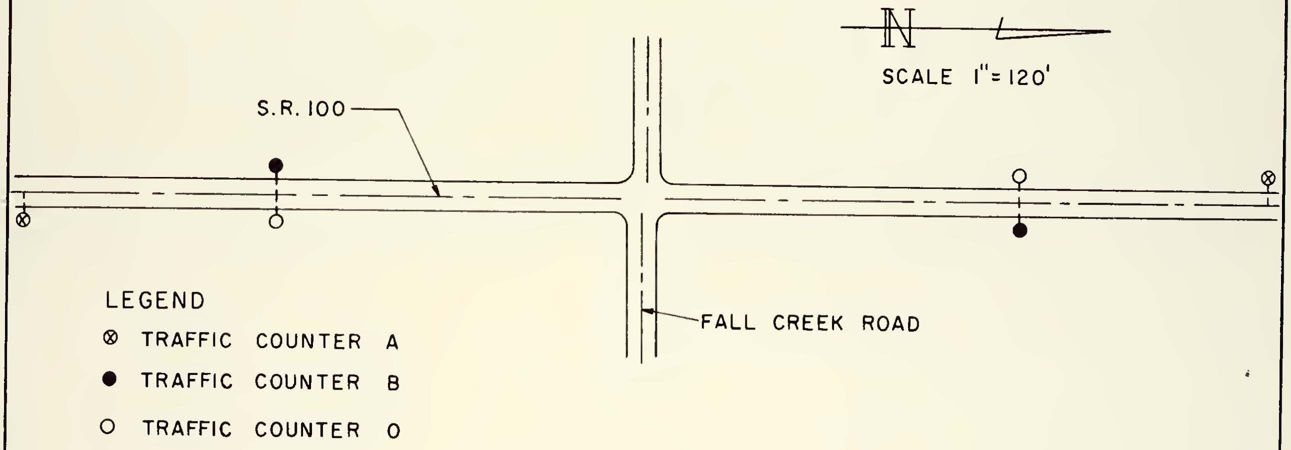

FIGURE 20 - S.R. 100 & FALL CREEK ROAD

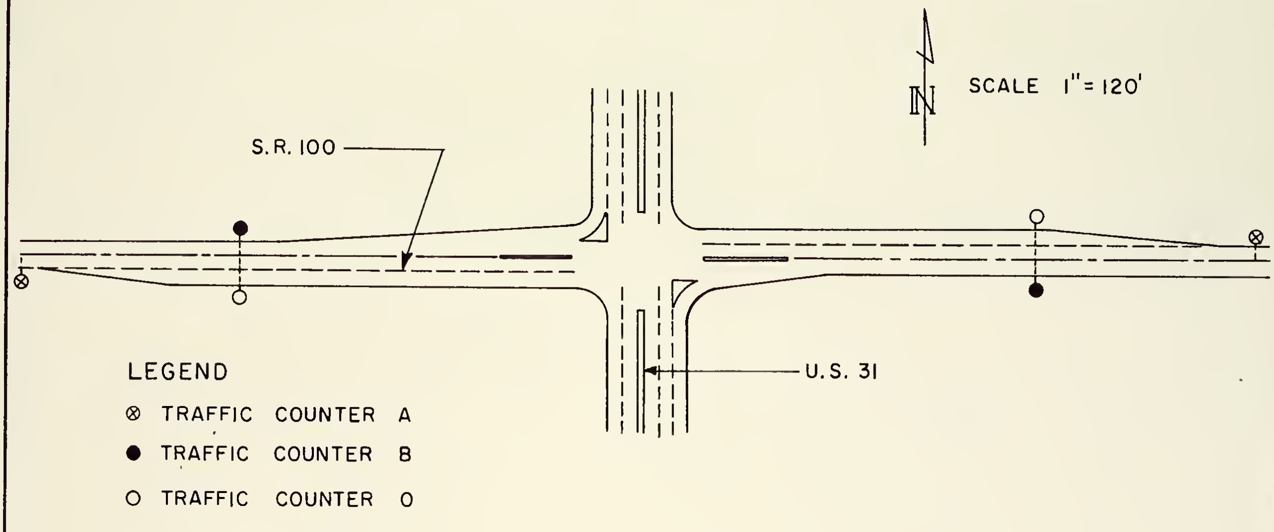

FIGURE 21 - S.R. 100 & U.S. 31

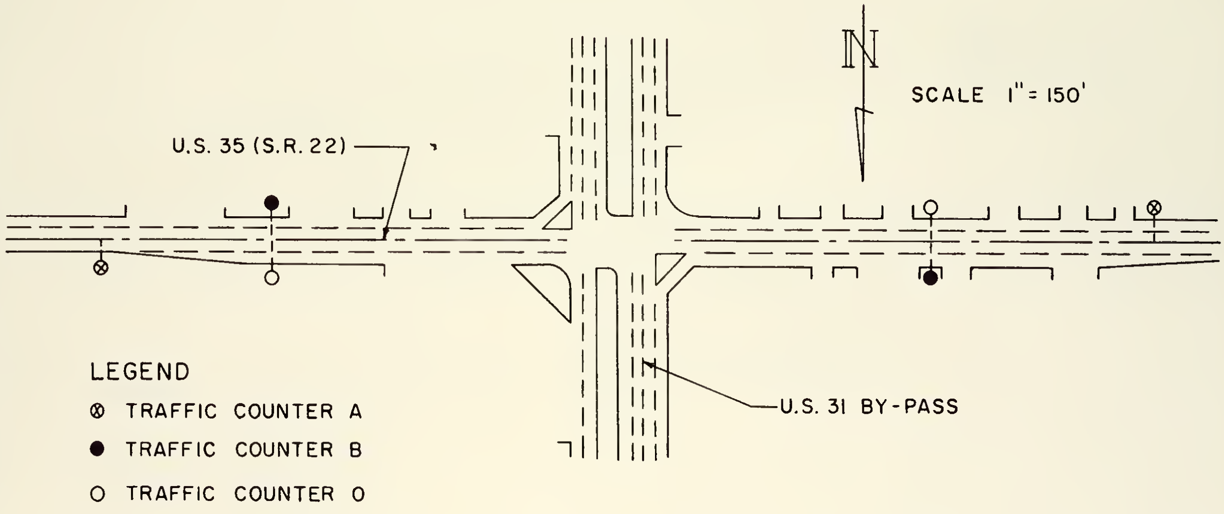

FIGURE 22 - U.S. 35 (S.R. 22) & U.S. 31 BY-PASS

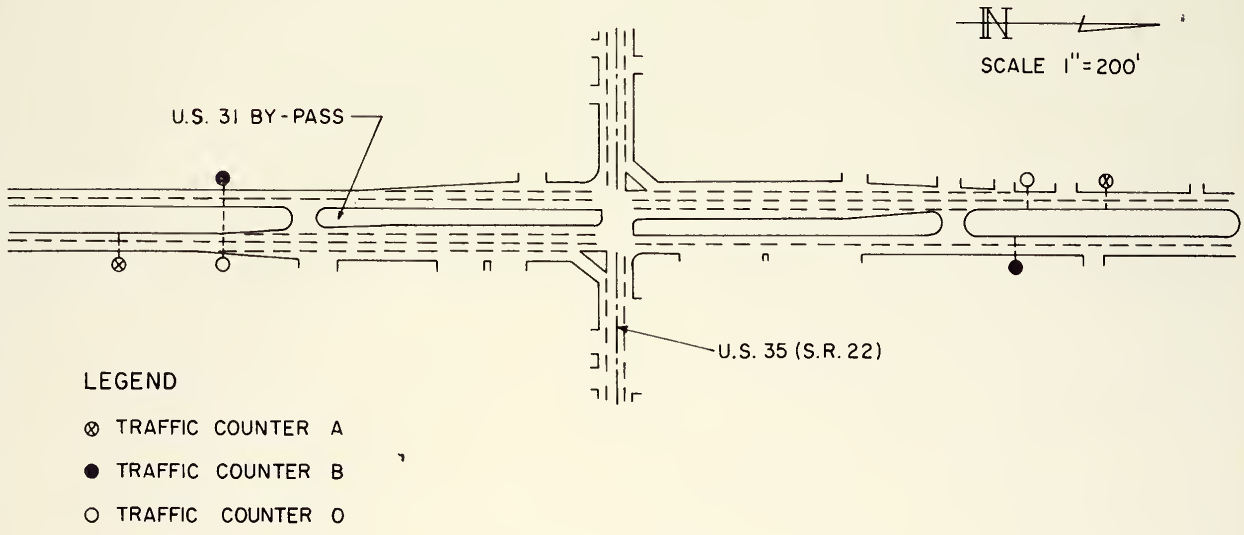

FIGURE 23 - U.S. 31 BY-PASS & U.S. 35 (S.R. 22)

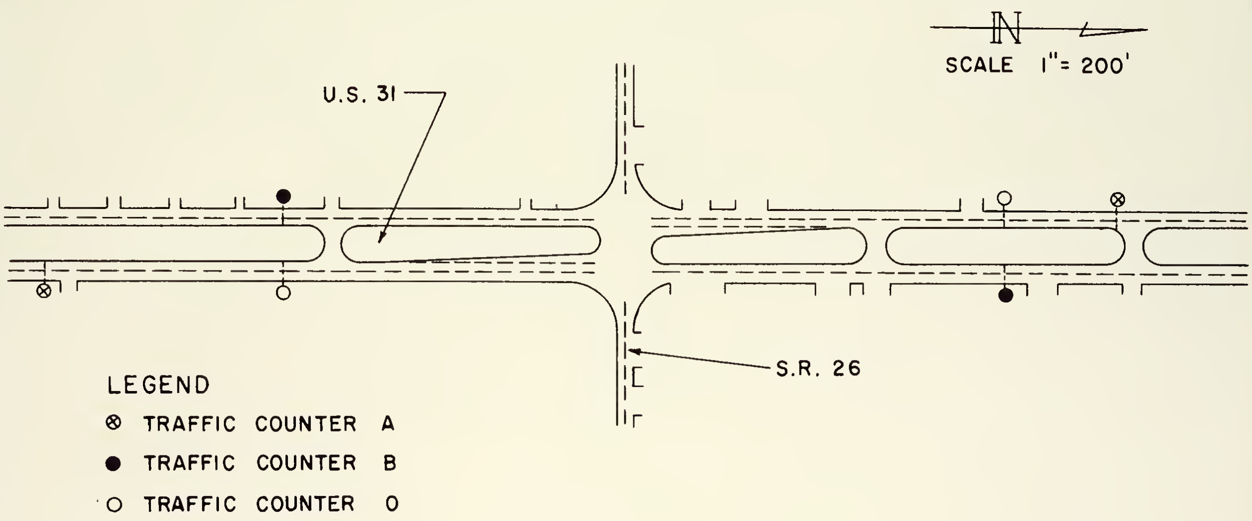

FIGURE 24 - U.S. 31 & S.R. 26

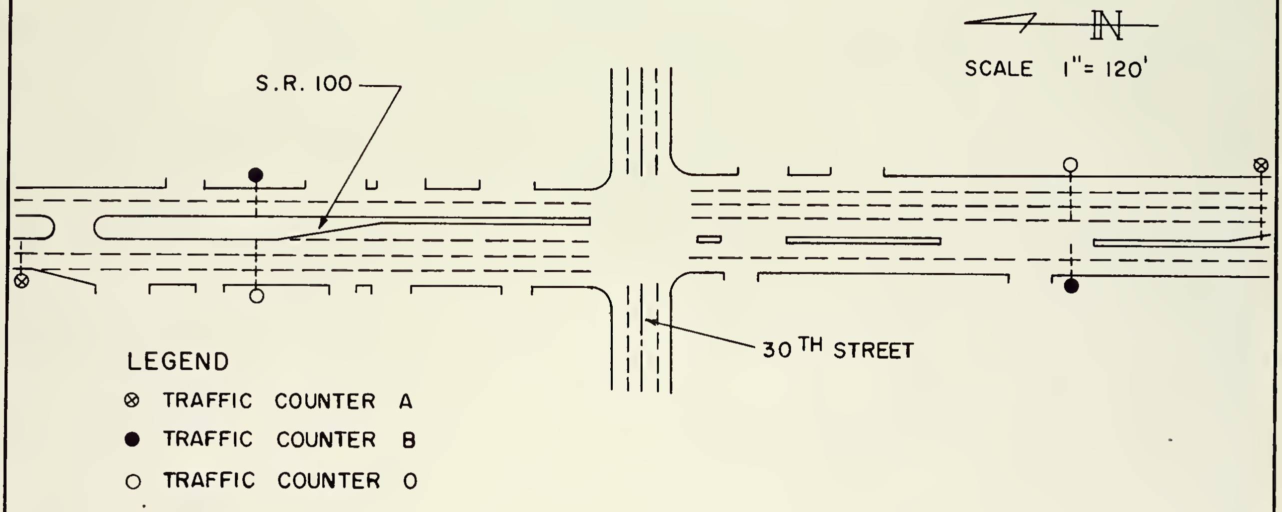

FIGURE 25 - S.R. 100 & 30TH STREET